ASTRONOMY

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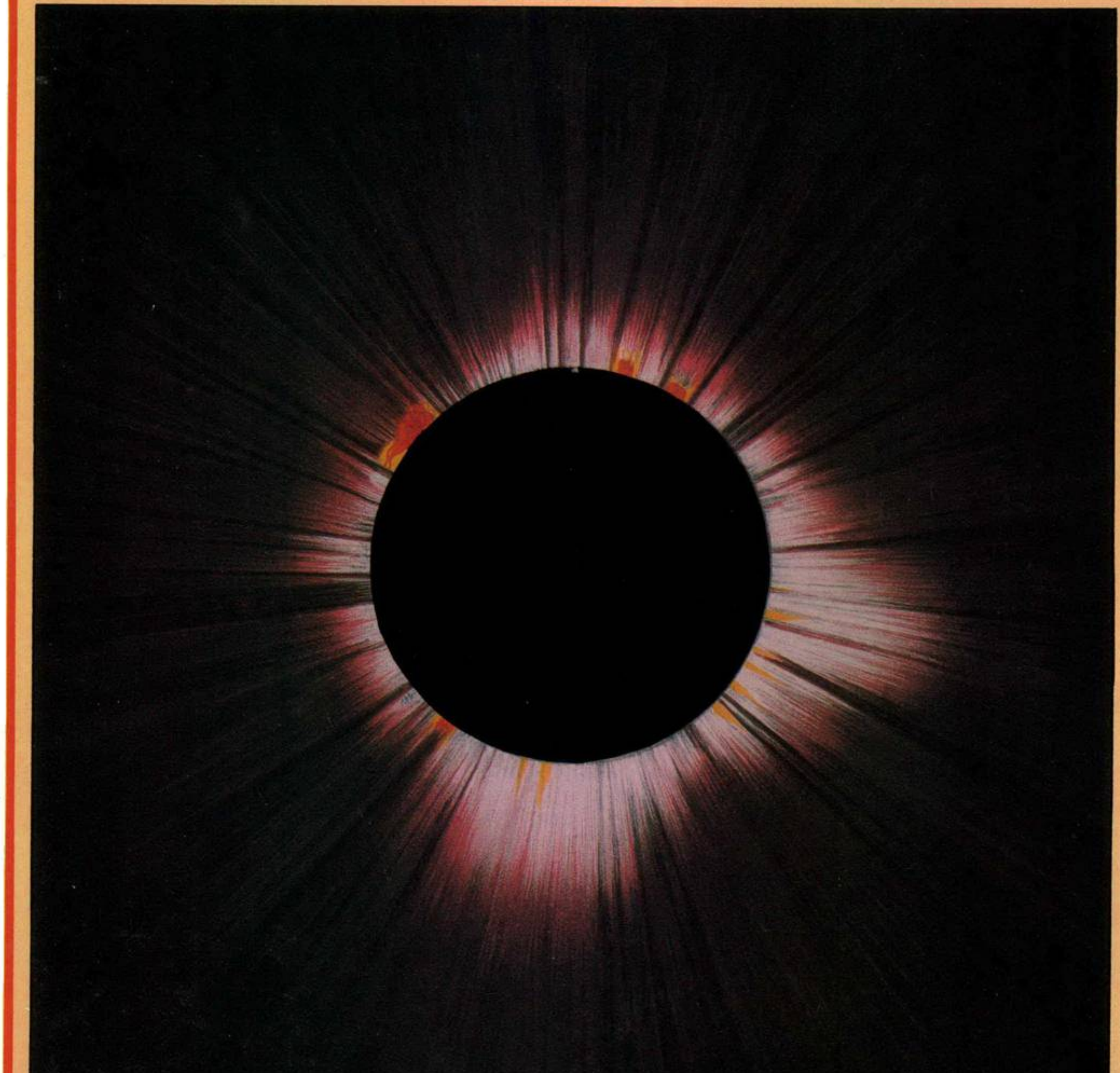
Solving the Mysteries of Venus

How to Photograph the Moon

An Interview with Bruce Murray



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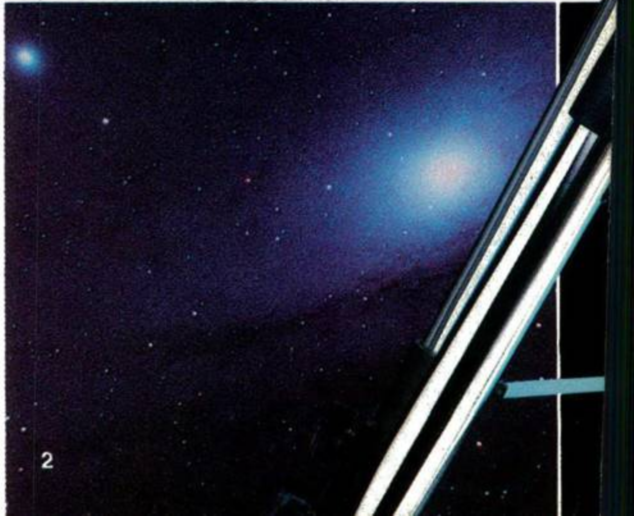

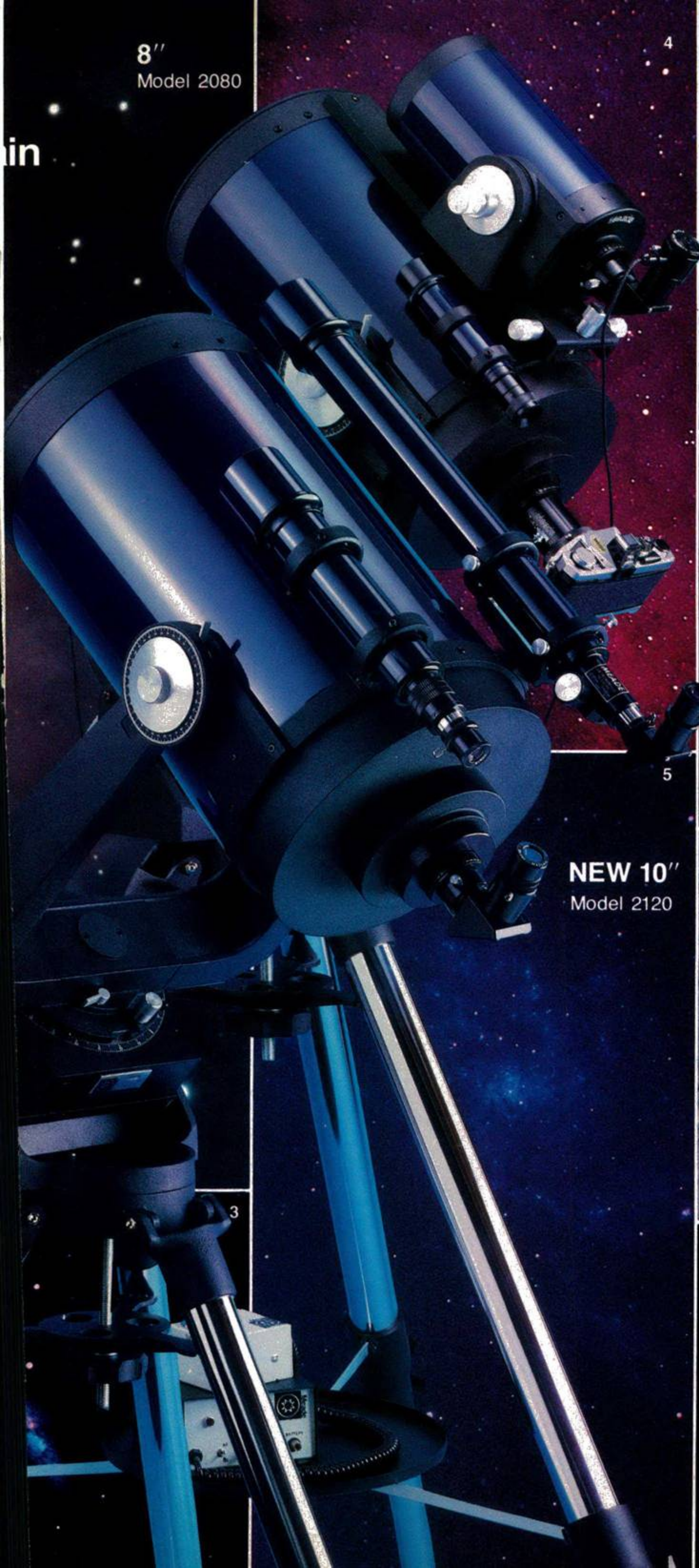

All astrophotographs shown on these pages were taken through off-the-shelf, unmodified Meade 8″ Model 2080 Schmidt-Cassegrain telescopes. For further technical details on these and many other astronomical photographs, send for your free copy of the Meade Schmidt-Cassegrain Astrophoto Brochure. (Alternately, the complete Meade 52-page General Catalog is available at $3.00 by First Class Mail and includes the Astrophoto Brochure at no additional charge.)

Key to Photographs
1, 2, 3, 5, 7 — Leo Henzl; 4, 6, 8 — Emery Hildebrand;
9 — John Sanford

1. Orion Nebula M42; exposure time 50 mins. **2.** Andromeda Galaxy M31; 60 mins. **3.** Galaxy M82; 60 mins. **4.** Milky Way in Sagittarius (50mm piggyback photo). **5.** Spiral Galaxy M33; 75 mins. **6.** Spiral Galaxy M51; 60 mins. **7.** Galaxy NGC 253; 40 mins. **8.** Omega Nebula M17; 40 mins.; **9.** Moon — Clavius region; 1-sec.

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6 Venus
by Bruce M. Cordell
15 Venus: On the Surface
by Van Kane
Forum 24 An Interview with Bruce Murray
Why We Need a Space Tug
Alone But Not Lonely
Eye on the Sky 34 Constellations Steal the Show
by Fred Schaaf
In Focus 40
Behind the Scenes 41
Gazer's Gazette 42 Learning the Fall Constellations
Photography in Astronomy 50 Focus on Luna
Equipment Atlas 58 Astronomy in the Garden
by Edmund A. Fortier
AstroNews 62
Astronomy Reviews 70
AstroMart 72
Stellar Frontiers 74 What Heats the Solar Corona?
by Leon Golub
The Backyard Astronomer 86 Capricornus

Cover: The pearly glow of the Sun's corona — shown in a U.S. Naval Observatory drawing of the August 7, 1869 eclipse — has long concealed a thorny problem for astrophysicists: Why is the corona over 100 times hotter than the solar surface next to it? This month's Stellar Frontiers probes the latest investigations into this paradox. In "Venus," we examine another heat problem: Why does our sister world, which started out much like Earth, now bake under a crushingly heavy atmosphere? Photo on this page by Roberta Loeper.

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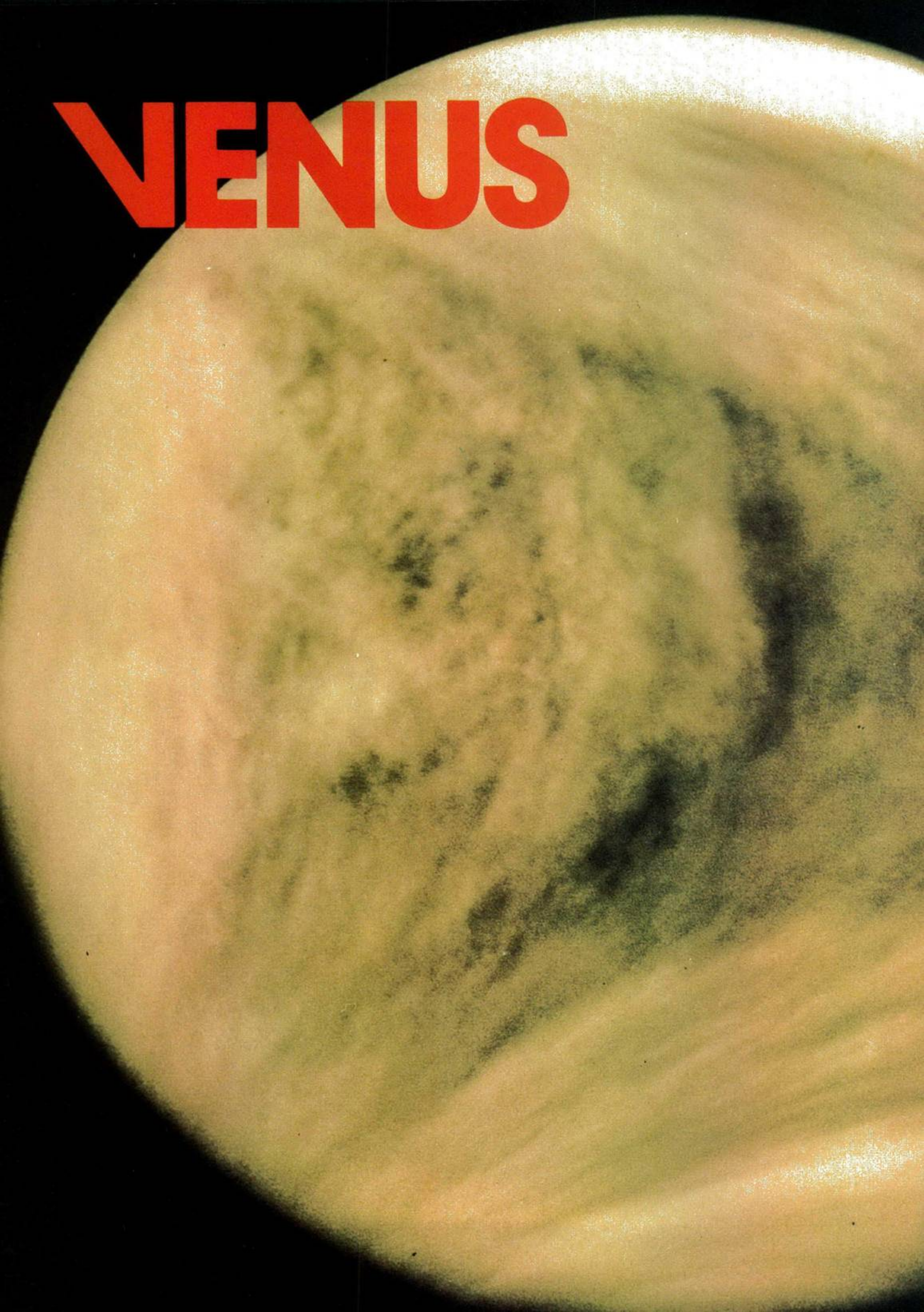
VENUS



NASA/Ames

space probes uncover the geology and history of a world

By Bruce M. Cordell

The planet Venus lies at the very forefront of planetary exploration. Venus, the Goddess of Love, the planet of clouds, the world of steaming swamps and jungles of science fiction, dubbed the "twin of Earth" by science popularizers. What has become of these romantic notions?

Venus has turned out to be quite different than we once thought it was. To a geologist, the similarity of the mass, radius, and density of Venus and Earth immediately suggests that Venus could mimic Earth's interior structure, composition, and tectonism. Yet the similarities only serve to heighten the puzzle of the planet's eccentricities.

Venus has a 243-day rotation period, and it rotates backward; it has no moon and no magnetic field. Venus is a dry planet while Earth is moist. Venus has a massive carbon dioxide atmosphere while Earth has a thin, nitrogen/oxygen atmosphere. Venus bakes with surface temperatures near 750 K — hotter than an oven — at pressures of 90 times that of Earth. So, although it is the most Earth-like of the terrestrial worlds, Venus remains the least understood rocky planet.

Nonetheless, Venus offers great potential for learning. It promises to teach us how our own Earth, and planets in general, actually work. Venus holds this promise because it could have been Earth-like, and might once have been Earth-like, but isn't now. And those differences raise compelling questions.

Interior Heat

Heat is a planet's life-blood. Its style of creating, storing, and losing heat determines a planet's past, present, and future. Volcanos, earthquakes, and other forms of tectonism such as folding, faulting, and building mountains are simply vigorous planetary attempts at cooling off.

Large terrestrial planets, such as Venus or Earth, typically start hotter and cool more slowly than small planets due to their thick layers of insulating rock. Small bodies, such as Earth's Moon, cool quickly. Larger planets remain volcanically active, as Earth has, for billions of years.

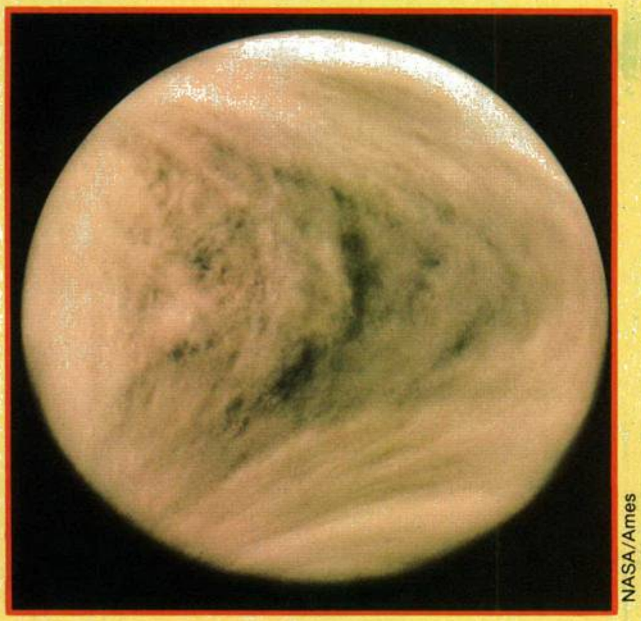
But how can we tell what's happening deep inside a planet? We can't do it directly, but surface features and topography imply an immense amount of information about what is — and has been — happening inside.

A planet's surface is the battleground between the interior forces of volcanism and tectonism that seek to elevate portions of the surface and create topographic relief, and the exterior forces of water and wind, that try to grind the surface into a flat desert. When we compare the two planets, we expect to find differences — and thereby find answers.

How do Venus and Earth lose their heat? What styles of tectonism and volcanism do they have? What

Venus and Earth:

Two Worlds Compared



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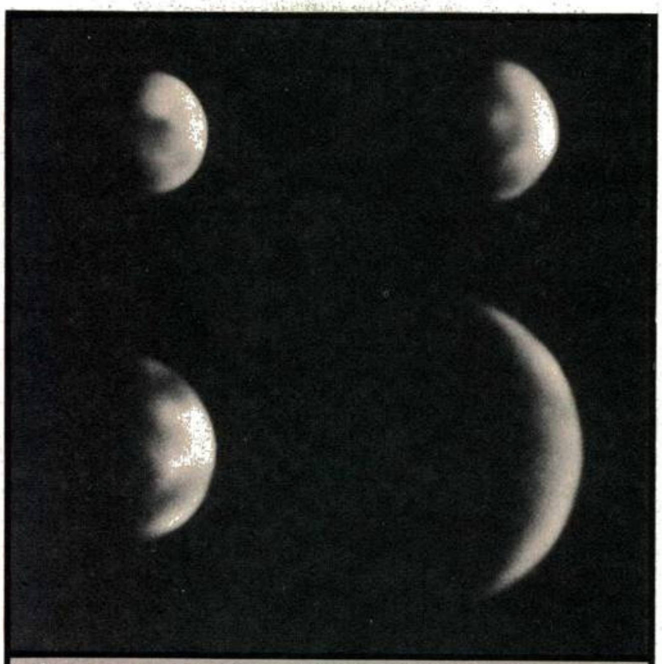
	Venus	Earth
Distance from Sun	0.723 A.U.	1.000 A.U.
Solar Energy Flux	3.73 cal cm^{-2}	1.95 cal cm^{-2}
Orbital Period	225 days	365 days
Diameter	12,103 km	12,756 km
Mass	4.87×10^{27} grams	5.98×10^{27} grams
Density	5.11 gm cm^{-3}	5.52 gm cm^{-3}
Surface Gravity	0.88 of Earth	—
Rotation Period	243 days, retrograde	1 day, direct
Composition	not known	nickel-iron core basaltic mantle silicate rock crust
Tectonic Style	hot spot	plate tectonics
Albedo	60%	37%
Atmosphere	97% carbon dioxide 3% nitrogen	77% nitrogen 21% oxygen 1% water vapor
Cloud Cover	100%	approx. 50%
Cloud Composition	sulfuric acid	water
Surface Pressure	90 bars 1400 psi	1 bar 15 psi
Surface Temperature	750 K 900°F	287 K 60°F
Surface Materials	basaltic rock	silicate rock
Magnetic Field	none	0.6 gauss dipole



Under the best seeing conditions, Venus displays only the vague changing marks in its upper atmosphere to telescopes on Earth. Lunar and Planetary Lab photographs courtesy the University of Arizona.

processes erode rocks and mountains away? What are their interiors like? How has Venus evolved geologically through time?

We are just learning the answers.

The Geology of Earth

How similar are Earth and Venus? If they were alike, the rather bizarre surface of Venus should be related to the principal tectonic feature of Earth: crustal plates. Our planet's surface is broken into a half-dozen cold, rigid, 100-kilometer thick lithospheric plates. They float on the warm, relatively plastic, partially molten region called the asthenosphere. The plates move slowly, at 5 to 10 centimeters per year, apparently driven by thermal convective motions of rock in the mantle, and by gravity.

Most terrestrial geologic action happens where plates collide. Earthquakes, volcanos, and mountains result from their massive slow-motion collisions. If, for example, a plate of heavy oceanic rock jams against a more buoyant plate of continental rock, it is forced back down into the interior. As it sinks, it becomes hot and eventually melts. The less dense molten rock rises and erupts through volcanos. This tectonic trauma, called subduction, can make a trench up to 11 kilometers deep in the ocean floor and an adjacent arc-shaped group of active, explosive volcanos.

When two continental areas collide, subduction cannot occur because these materials are too buoyant to be forced down. Instead, the continents crumple. Enormous folded ranges of mountains — the Rockies and the Himalayas — thrust up to become the legacy of horizontal plate motions.

Other plates, particularly those that meet in the centers of oceans, move apart. Molten rock from the interior forces its way up between them. New crust is created. Long straight ridges elevated hundreds of meters above the surrounding ocean floor mark the sites of sea-floor spreading. The mid-ocean ridges of Earth form a global system over 60,000 kilometers in length. In contrast to subduction zones where lithospheric material is consumed, mid-ocean ridges are a source of new crust.

Although most terrestrial volcanic activity occurs at a plate boundary, some activity does not. Volcanic "hot spots" overlie plumes of molten magma rising from unknown depths. The heated rock melts through the overlying crustal rocks and breaks through to the surface. Plumes originate deeper than the plate motions so, as Earth's crust moves over a hot spot, it may leave a chain of volcanos. The Hawaiian islands are the Earth's best-known chain.

The Surface of Venus

But what do we know of the surface of Venus? NASA's Pioneer Venus spacecraft and Earth-based radar have now revealed a planetary surface that, although unique, has been affected by recognizable tectonic and volcanic processes. More than 40 months of Pioneer Venus radar altimetry involving over 200,000 measurements of surface topography and gravity show that the venusian surface, while not flat, is less varied than Earth's. Some 70% of the surface, the regions we call rolling plains, lies near the mean planetary radius.

In distinct contrast, most of Earth's surface exists at one of two elevations. The high elevations are the continents, and the low elevations are the ocean basins. Their average elevations are more than 4 kilometers different. We often forget the ocean basins simply because they are filled with water, but they are an important feature of our planet.

About 20% of the venusian surface is lowland — roughly circular areas as much as 1,500 meters below the mean radius of Venus. The venusian lowlands are irregular to roughly circular in shape and typically several hundred kilometers across. Many lowlands look suspiciously similar to the enormous, ancient impact basins known on all the other terrestrial planets.

Finally, the remaining 10% of the Venus surface is highland. The highest point on the planet, the protuberance known as Maxwell Montes, towers 11 kilometers above the average of the rolling plains.

Venusian highlands roughly resemble Earth's continents. Within Ishtar Terra, the region containing the Maxwell Montes, a subregion known as Lakshmi Planum abruptly rises 4,000 meters from the rolling plains, and is guarded by 3,000 meter-high marginal mountain ranges. Lakshmi, which at 2,500 kilometers in diameter is twice as large as Earth's Tibetan Plateau, is superficially similar. The Tibetan Plateau is a region rapidly forced upward due to the collision of two continental plates. Eastern Ishtar is the site of the Maxwell Montes which exceed even Mt. Everest in elevation. Ishtar could be a venusian version of the

Himalayas — the result of the head-on collision of two continental plates.

Another enigmatic highland, Aphrodite Terra, dwarfs Africa. Aphrodite sprawls 10,000 kilometers along the venusian equator, split by several rifts, or giagantic cracks, up to 3,000 meters deep and 1,000 kilometers long. Could Aphrodite be analogous to the East African Rift system where that continent is slowly tearing itself apart?

The Craters of Venus

Even the seemingly mundane plains are not featureless. Dozens of roughly circular, randomly distributed structures between 20 and 80 kilometers in diameter clutter its expanse. The obvious and tempting conclusion is that the circles are meteorite impact craters. But this interpretation is tentative, and few planetary scientists seem committed to it. Craters, of course, imply an ancient and relatively unchanged landscape. If Venus had plate motions for most of its history, few craters could have survived.

Still, Venus must have been a victim of the same planetesimal bombardment that other planets experienced near the end of their formations. The effects of a 90 bar atmosphere would have been profound, and craters smaller than 20 kilometers should be sparse because the bodies that produce them could not survive passage through the dense atmosphere. Furthermore, venusian craters should look different. Instead of flying out in all directions, rubble ejected from a venusian crater during impact would fall back close to the crater due to the difficulty of penetrating the thick atmosphere.

On close inspection, we also see that many of the circular features are not perfectly round. Perhaps the high temperature of the surface allowed the rocks to soften and undergo plastic deformation, distorting the original shape of the craters — if indeed the circles are craters.

What else could they be? We already suspect Venus has volcanos because the radar shows mountains with rough surfaces. The circles might be other volcanic features, possibly shallow calderas, unusual because the high surface temperature would allow lava to flow long distances on the Venus surface.

Oddly enough, we know that any circular structures larger than 300 kilometers in diameter are not impact craters. Since large craters must have formed, we might wonder what happened to them? Calculations which assume reasonable properties for venusian surface rocks show that giant impact craters would have "relaxed" over the 4-billion-year period since they were formed. The big craters simply, and ever-so-slowly, slumped away under their own weight in the oven of Venus. This has interesting implications for the history of the Venus atmosphere. Since it takes billions of years to relax a large crater, Venus must have been as hot as it is now for most of its history.

Venus
as a heat machine

Venus is, in a large sense, the twin of Earth. It is nearly the same size and mean density and, from the Russian results, we know it has about the same radioactive heat content. The two planets ought to be about the same as thermal engines.

The means by which Earth expels its internal heat shapes its surface. Sea-floor spreading, which drives terrestrial plate tectonics, merely reflects the particular style by which Earth expels its internal heat. That makes the study of Venus interesting because it gives us another planet to test and compare with Earth. We want to see if plate tectonics always operates on planets that have virtually the same properties.

However, we scientists now don't think that sea-floor spreading is currently active on Venus, for a number of reasons.

First: we simply don't see the physiography and topography that sea-floor spreading creates on Earth. It's totally absent on Venus.

Second: the lithosphere of Venus, because of the high surface temperature, is too buoyant to sink into the mantle. Subduction, a prerequisite for plate tectonics, can't happen on Venus because crust must be heavy enough to sink back into the planet's interior.

Third: sea-floor spreading, because of the high surface temperatures on Venus, would be a very inefficient way for heat to escape the interior of Venus. Earth is cooler, so sea-floor spreading operates as a very efficient means of cooling the interior. On Venus this doesn't seem to be the case.

How might Venus remove its heat? A secondary mechanism on Earth, called *hot spot dynamics*, may dominate on Venus. Hot spots are places where long, deep, convective upwellings from the mantle reach the base of the lithosphere and expel their heat. Quite often they're associated with the volcanism of the surface. You are probably familiar with these areas on Earth — Iceland is one; Hawaii is the other.

If sea-floor spreading on Earth were to stop, the hot spot mechanisms probably would become the main way that Earth would expel internal heat. Since we don't believe that sea-floor spreading works on Venus, hot spot tectonics probably removes internal heat from Venus.

We have seen two things that, I think, support the hypothesis that most of the topography on Venus is composed of hot spots in various stages of evolution. Radar mapping indicates that the two areas of the freshest, most competent rocks are, in fact, over the Beta and the Scorpion Tail area of Aphrodite, suggesting that fresh rock is being created there.

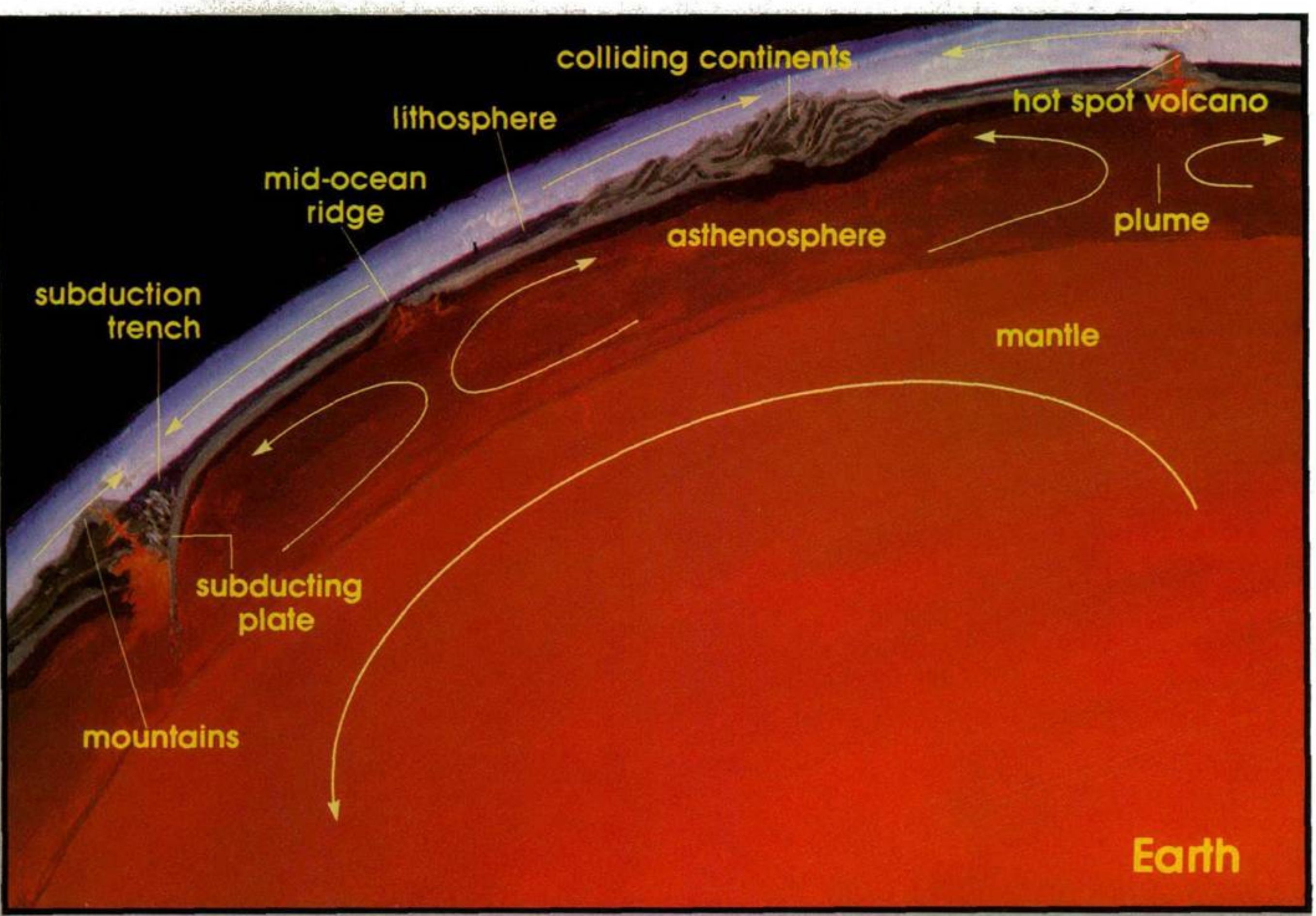
Under Beta, in particular, and eastern Aphrodite, the density anomalies supporting the topography are very deep, down to 1000 kilometers, and certainly no less than 500 kilometers.

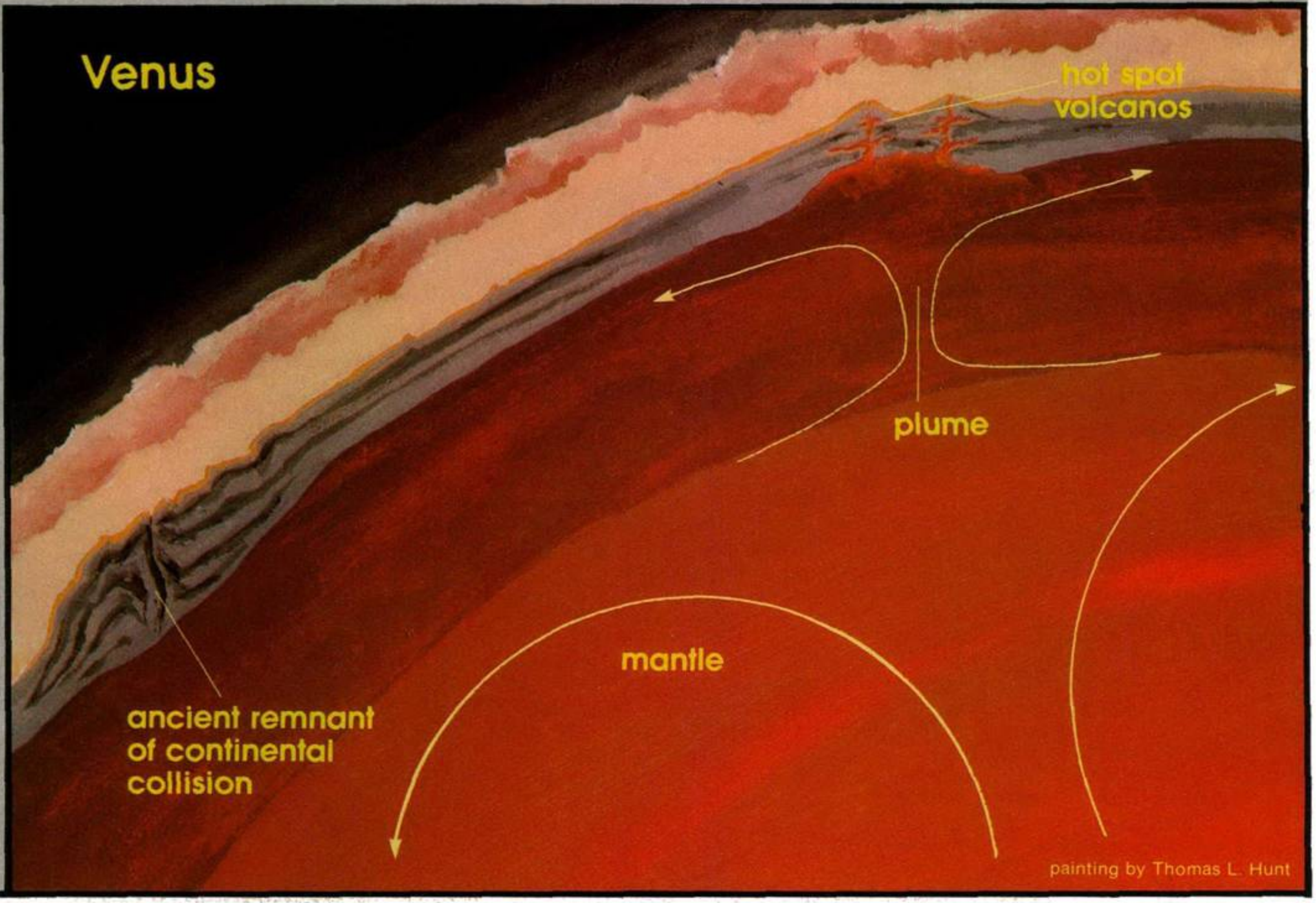
From what we understand about planets, there's simply no way in which these anomalies could be supported by the strength of the interior of the planet. They are probably supported by dynamic mechanisms, upwellings of the mantle. This adds credence to the hot spot hypothesis.

Secondly, Fred Scarf has found that active lightning appears over these places, which implies volcanic activity. So we seem to be seeing a planet which is active today. It also must have volcanism going on. Its topography appears to be shaped by hot spot tectonics.

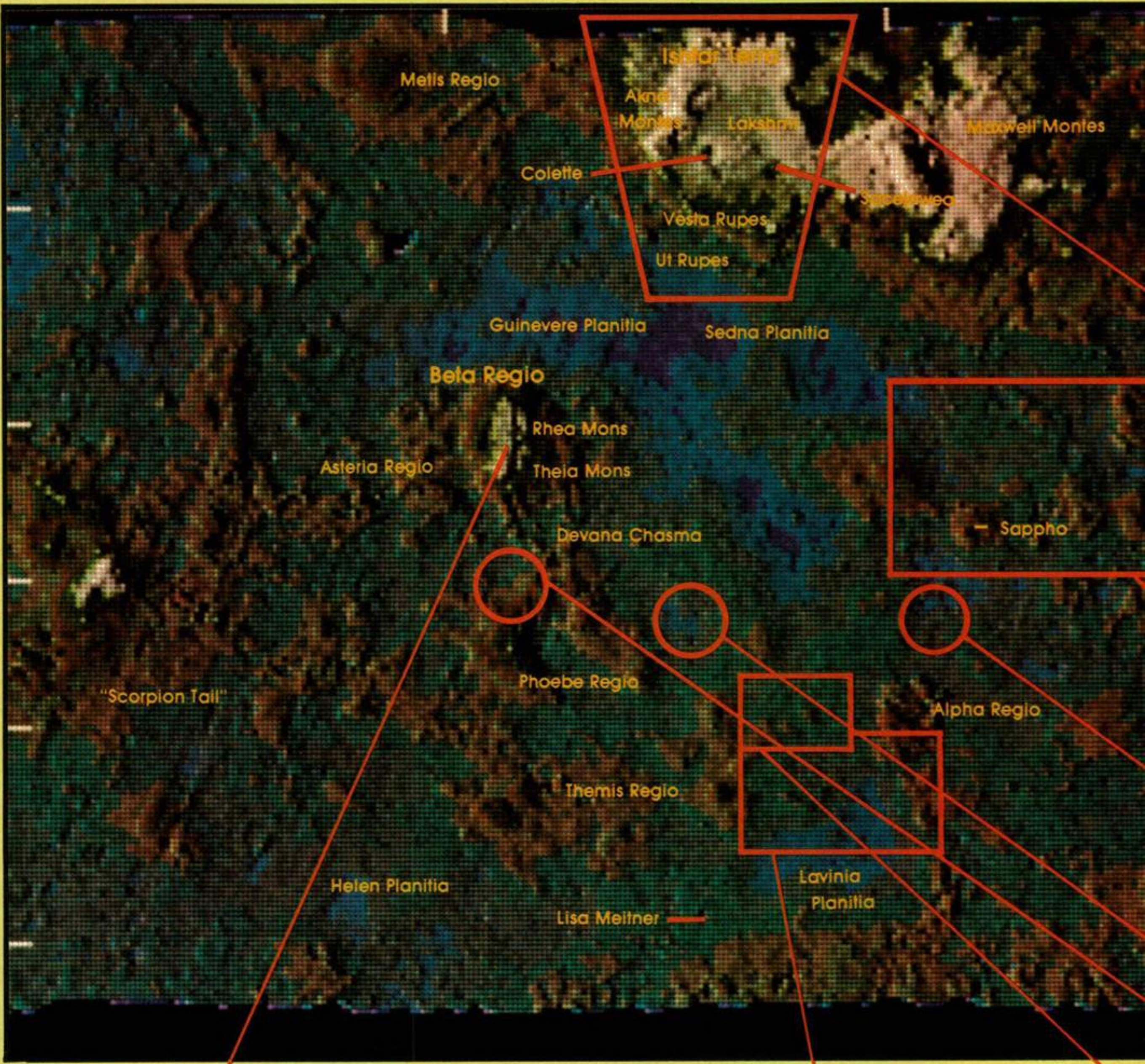
Finally, let me comment on Ishtar. It seems to be different, more like a terrestrial continent than any other region on Venus. We think we know how Beta and Aphrodite work, but how Ishtar formed is still enigmatic.

Based on comments made by
Dr. Robert D. Reasonberg
Massachusetts Institute of Technology


colliding continents
lithosphere
hot spot volcano
mid-ocean ridge
plume
asthenosphere
subduction trench
mantle
subducting plate
mountains
Earth


Venus
hot spot volcanos
plume
mantle
ancient remnant of continental collision

painting by Thomas L. Hunt


Ishtar Terra
Akna Montes
Lakshmi
Maxwell Montes
Metis Regio
Colette
Sacajawea
Vesta Rupes
Ut Rupes
Guinevere Planitia
Sedna Planitia
Beta Regio
Rhea Mons
Theia Mons
Asteria Regio
Devana Chasma
Sappho
Phoebe Regio
"Scorpion Tail"
Alpha Regio
Themis Regio
Helen Planitia
Lavinia Planitia
Lisa Meitner

Pioneer Venus has been an exciting project because of the vast ensemble of data that's suddenly become available. Although we've been flooded by good things — always a delightful position to be in — I'm going to limit my discussion to results of a few studies that we have recently conducted on Beta. Beta is a high region in which we find an exceedingly high gravity field. This indicates irregularities below the surface.

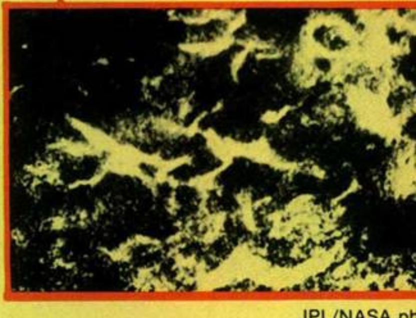
There are some classical, fairly simple models that one would like first to test in any region of irregular gravity. One of these, the simple Airy compensation model, proposes that when there is a mass sitting on the surface, something which you see in the topography, then someplace below the surface there is a compensating region of low density. In the Airy model, mountains float like icebergs. When these counterbalance properly, we say we have *isostasy*.

But the analysis that we have done shows that Beta is *not* a case of simple compensation between the buoyant mass below the surface and the mass sticking above the surface. Whatever the final description of that region is, it's not one of the easy ones that you'd get out of the textbook.

Another thing we've looked at in this region is the difference between the gravity that we observe and the gravity that we expect from a simple model. We have found a long trough in the gravity field which corresponds to a valley in the topography east of the main peak of Beta.

We suspect that the gravity anomaly trough represents a consoling function beneath the surface, something which has been, in some sense, responsible for the development of the valley. This suggests Beta is a dynamic region, a region in which deep mantle convection affects the surface, and that Beta is, therefore, a fairly young region.

Based on comments by Dr. Carl Bowen, Woods Hole Oceanographic Institute



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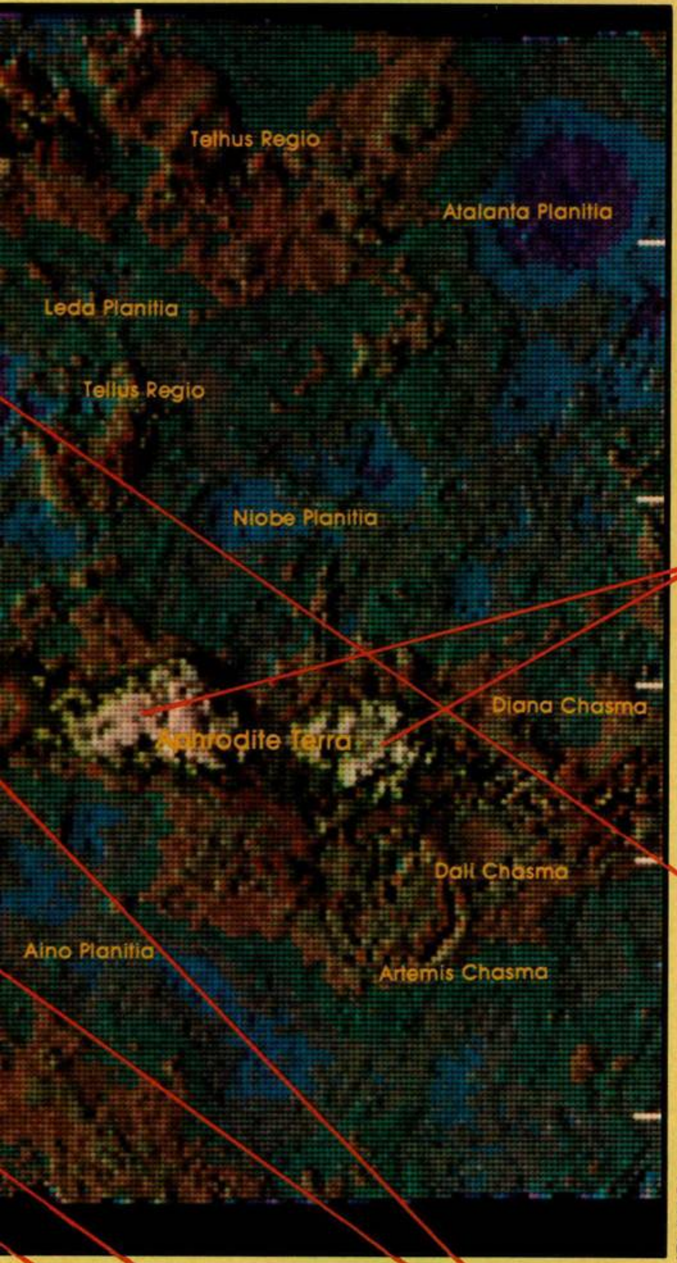


JPL/NASA map image

Venus

probing a planet

On gravity maps of the Earth, you don't see the topography or the location of the continents. Over the last two years, I've reached the conclusion that the gravity anomalies we do see on Earth are due primarily to variations at the core/mantle boundary deep within the Earth.

In contrast, when we look at the gravity field of Venus, we find anomalies at locations that coincide with the locations of Aphrodite, Ishtar and Beta Regio. In that regard, there's quite a contrast between Earth and Venus.

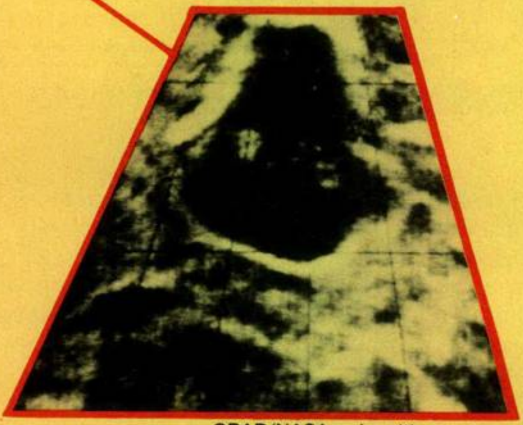
For Aphrodite, which I've concentrated my study on, the gravity anomaly is much larger than the anomaly we would get from a comparable continent on the Earth — about ten times greater.

We've compared Venus to a series of crustal models, and we find very good agreement between the gravity data, topography, and models when the crustal thickness is about 50 to 60 kilometers — depending on what density one assigns the crust. This would make the crust of Venus approximately twice as thick as Earth's.

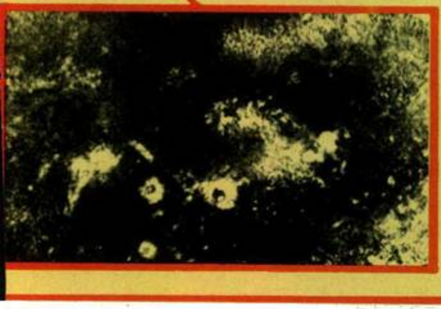
The picture we have for Aphrodite is that it has a 60-kilometer thick crust — maybe slightly more — and it's not, or at least need not be, dynamic. Most of Aphrodite may consist of light material floating in the crust, possibly formed from a "scum" that rose to the surface during the differentiation of the planet early in its history.

Beta has a much higher gravity field for its topography, so it may require some other mechanism, possibly dynamic, to support it. It seems that on Venus there are at least two different kinds of topography. One kind may be residual material, slag deposits, leftovers from the differentiation of the body — that may be much of Aphrodite. For the other kind, we may have active volcanism — like Beta or the eastern end of Aphrodite — that's making high mountains even now.

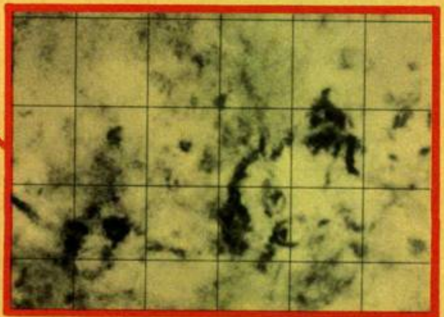
Based on comments by Dr. Roger Phillips, Lunar and Planetary Institute



ORAD/NASA radar altimetry image



Arecibo Observatory/NASA photo



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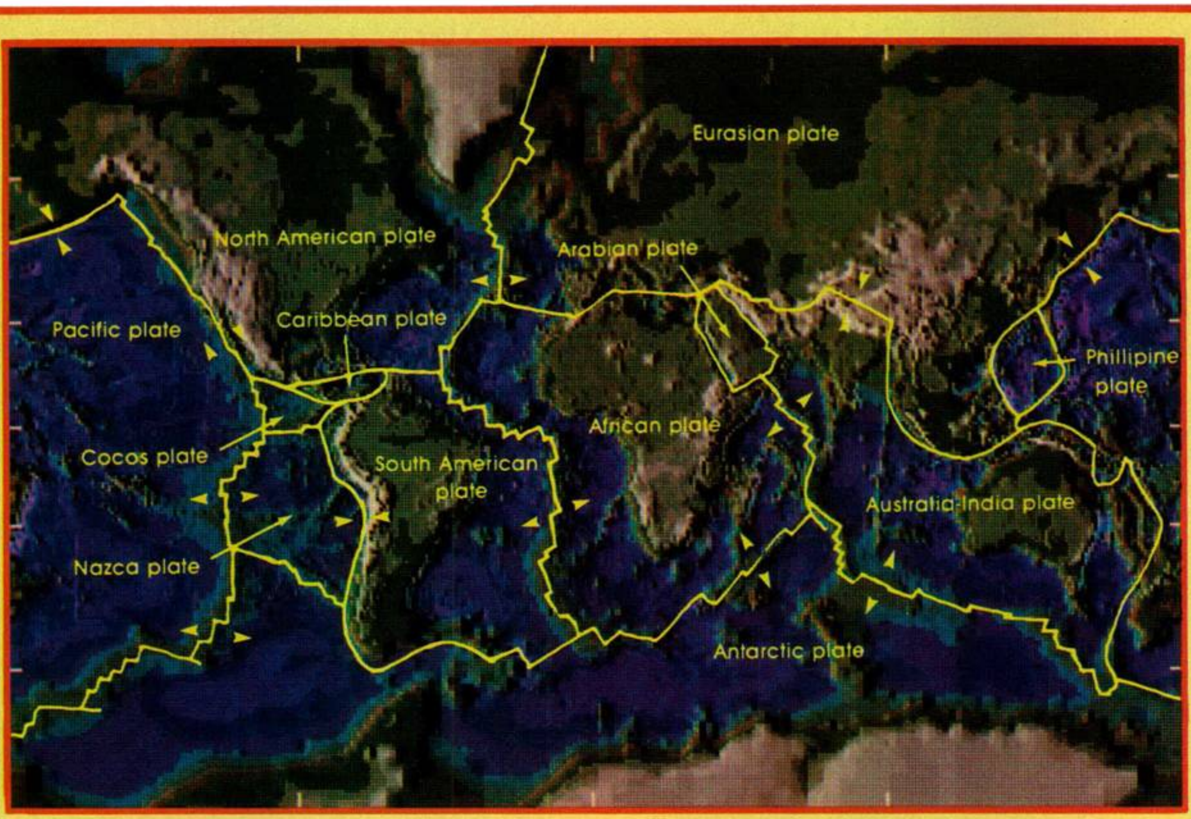


NASA/JPL

Terrestrial plates move apart at sea-floor ridges, including the ridge in the center of the Atlantic Ocean where new crust is being made. They move together at subduction zones such as the trench on the western side of the Andes, and where continents collide to form mountains like the Himalayas. Map courtesy NASA/JPL.

Venus

geology of a world

Compositional Clues

Although spacecraft and Earth-based topographic data are most important in deciphering the vexations of Venus, plenty of other clues help in constructing the history of the planet. Prime lines of investigation are the composition of the atmosphere and rocks. We have a growing body of data, but exactly what it means remains unclear.

Venus' atmosphere, for example, has only one-third the abundance of argon-40 as its terrestrial counterpart. Argon-40 is the radioactive decay product of potassium-40, a natural isotope of potassium, an element which is scattered throughout crustal rocks. If Venus and Earth formed from the same basic materials, as we think they did, their atmospheres should have roughly the same argon-40 content.

So, although the argon-40 deficiency could be due to a deficiency in the amount of potassium incorporated in Venus at the time of its formation, it seems unlikely. The ratio of potassium to uranium, an element which is presumably not depleted, is the same for both Venus and Earth. However, the deficiency could lie in the release of argon-40 from the rocks. If the effects of volcanism, tectonism, and surface weathering of rocks — processes which release argon-40 from the rocks into the atmosphere — were not very effective, then Venus would appear to have less argon-40. This suggests Venus has been less active than Earth over its whole history.

The Soviet Venera 8, 9, and 10 spacecraft survived the descent to the bottom of the planet's "ocean" of carbon dioxide and made the first direct measurements, via spectropscopy of the gamma rays they emit, of radioactive uranium, thorium, and potassium concentrations in the crust of Venus. Preliminary analysis suggests a more diverse distribution of U, Th, and K than on Earth. Perhaps the surface rocks of Venus are less "mixed" than Earth.

The recent X-ray fluorescence data from Venera 13 and 14 reveal two distinct patterns of elemental abundance. One pattern, obtained by Venera 13, is similar to terrestrial basalts in continental areas. The other, from Venera 14, resembles the terrestrial ocean basins. The gamma ray data from Venera 8 suggested typical terrestrial continental rocks, rocks like granite, hinting that at least three terrain types exist on Venus. The two Russsian landers planned for 1986 may help settle the question.

Tectonic Style

What have we learned from radar images about the tectonic style of Venus? If Venus is indeed an active Earth-like planet, the signatures of plate tectonics — an ocean ridge system, volcanic subduction arcs and plunging trenches, and collisional fold mountains — should all be present. Are they?

If a topographic map of Earth is smeared to the resolution of Venus images, fine details are blurred but the large picture remains relatively clear. Major features — mountain belts such as the Rockies, the Hawaiian volcanic bulge, the East Pacific Rise ocean ridge, trenches, and even medium-scale features like the east-west fractures on the eastern Pacific floor — are unmistakable signs of plate tectonics. If venusian counterparts exist, we should see them.

But it seems that we don't.

Is Venus therefore unlike the Earth? Why, we must ask ourselves, does Venus *not* show features of plate tectonics? What makes Venus so very different from Earth? Might there be reasons why plate tectonics could be impossible for Venus?

Venus displays an insidious individuality. The crust of Venus, as a result of being 450°C hotter and much drier than Earth's, is lighter — some 12% less dense than Earth's crust — and conducts heat differently than Earth's crust. Perhaps these very properties of the rocks prohibit plate activity?

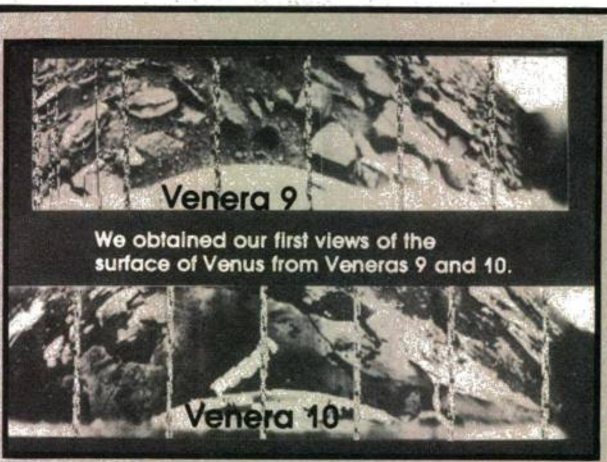
When terrestrial ocean bottom basaltic crust is subducted, mantle pressures crush it into a more compact, heavier rock called eclogite. Eclogite sinks into the mantle and helps drag the rest of the plate down with it into the mantle. However, the transition of basalt to eclogite cannot happen if the basalt is too hot, so it appears that the elevated temperatures on Venus could prevent a similar transformation there — suggesting that subduction is unlikely on Venus.

The moisture content of venusian rocks is also important. Water weakens rocks on Earth and lubricates joints where rocks must slide against other rocks. Sliding is essential to plate motions. But venusian rocks are not soggy as terrestrial rocks are — our best guess of Venus' atmospheric history suggests Venus lost its crustal and atmospheric water during a catastrophic, super-hot divergence from an Earth-like evolutionary track. Dry rocks could bring mobile plates to a screeching halt.

We can also consider whether plate tectonics could be an efficient thermal process on Venus. Remember, plate tectonics is a mechanism whereby a planet can cool itself off. But because Venus is hot and oceanless, spreading "ocean" ridges can only disperse one quarter the heat the same process disperses on Earth. Assuming that they have similar abundances of radioactive elements and therefore similar internal generation of heat, Earth loses 70% of its internal heat through plate tectonics while Venus could bring only 15% of its internal heat to the surface through plate motions. Even if Venus *did* have plates, it would still need other ways to cool off.

Finally, the high surface temperatures should have softened venusian rocks, resulting in a relatively rapid smoothing out of topographic variations. If nothing makes new hills and valleys, there should be none left on the planet. Nonetheless, we see them there.

So, what causes the venusian hills and valleys? There are three major possibilities: 1) violent collisions of plates, 2) a contraction of the lithosphere causing surface wrinkling, or 3) hot spot volcanism



We obtained our first views of the surface of Venus from Veneras 9 and 10.

NASA

Venus

on the surface

Late last winter men from the planet Earth stood — albeit vicariously — beneath the clouds of the veiled planet Venus and looked around. On March 1 and 5, Soviet robot spacecraft Venera 13 and 14 touched down at sites 962 kilometers apart on the surface of Venus. For a total of 184 minutes, they photographed their surroundings, tested the soil, listened to the wind, felt for earthquakes, and radioed data back to Earth. Scientists in the USSR continue to analyze this data. What they've learned so far hasn't shaken anyone's view of Venus, but it's begun to allow humans to know the second planet from the Sun on intimate terms.

The Venera series began in 1961 with the first, unsuccessful, attempt at interplanetary flight. Venera 8 made the first landing on another planet in 1972. Three years later, Veneras 9 and 10 returned the first photographs ever made from the surface of another planet. Veneras 11 and 12 arrived at Venus in 1978, but their instruments failed in the extremely hot environment.

Those missions taught Soviet engineers to design probes for the oven-like surface temperatures of the planet. In planning Veneras 13 and 14, they concentrated on improving the instruments, making the atmospheric measurements more sensitive, and equipping the landers with cameras that not only recorded more detail, but could also take pictures on both sides of the spacecraft and return photos in color. And, most significantly, these probes were made to bring samples of rock and soil inside themselves for chemical analysis.

After the long interplanetary journey, each lander's trip to the surface began two days before the touchdown as it separated from the mother ship that carried it to Venus. After plunging into the upper atmosphere and slowing down, each probe jettisoned its heat shield at 64 kilometers altitude and began relaying data to the mother craft overhead. For the next 18 kilometers of the hour-long descent, the Venera rode beneath a parachute, falling slowly through the cool upper atmosphere in order to study it.

When each probe finally reached regions of high temperature, it released its parachute and fell freely so it could reach the ground quickly before the fierce heat seeped into the insulated spherical electronic compartment. The increasingly thick air — at the surface it has 1/14th the density of water — helped break the plummet. At roughly 20 kilometers per hour, though, the impact of landing wasn't gentle.

The Veneras were sent to answer three broad classes of questions: What is the composition of the atmosphere? What is the composition of the rocks? What is the surface geology?

Planetologists use the relative abundances of the chemically inert gases — argon, krypton, xenon, and neon —

Venus

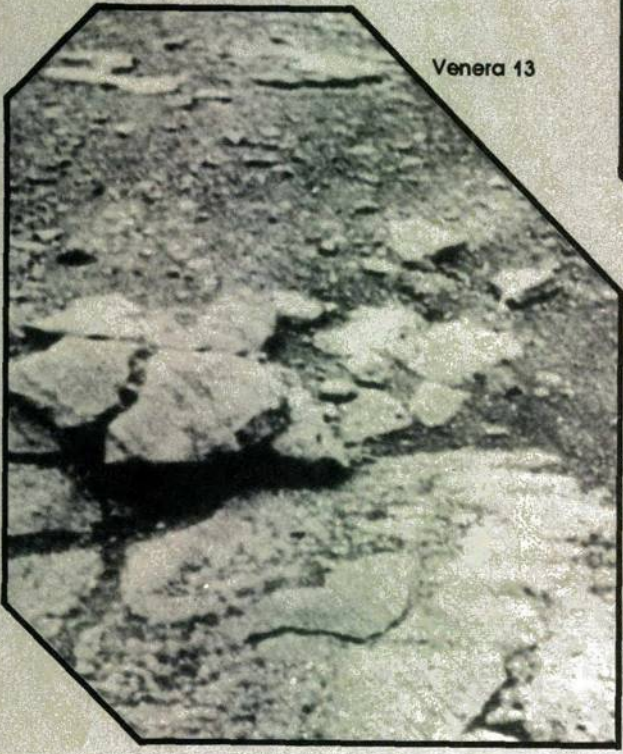
the rocky landscape

as clues to deduce how a planet formed and where its atmosphere came from. These gases generally do not combine with other elements to form chemical compounds; they remain in the air. More active gases may escape or be removed.

In 1978, American and Soviet probes found Venus has far more inert gases than either Earth and Mars, but the measurements disagreed on how much more. Soviet scientists believe that Veneras 13 and 14 will provide the most accurate measurements made so far when the data are fully analyzed — then theorists can try to determine why Venus' birth differed from the births of its planetary neighbors.

One major question left from earlier missions was the type of chemical reaction taking place in the lower atmosphere. Technically, the issue is whether the reactions are oxidizing or reducing. Iron, for example, will rust in an oxidizing atmosphere like Earth's, but remains rust-free in a reducing atmosphere. Soviet researchers hope that once they identify two new gases discovered during the descent, they can answer this question.

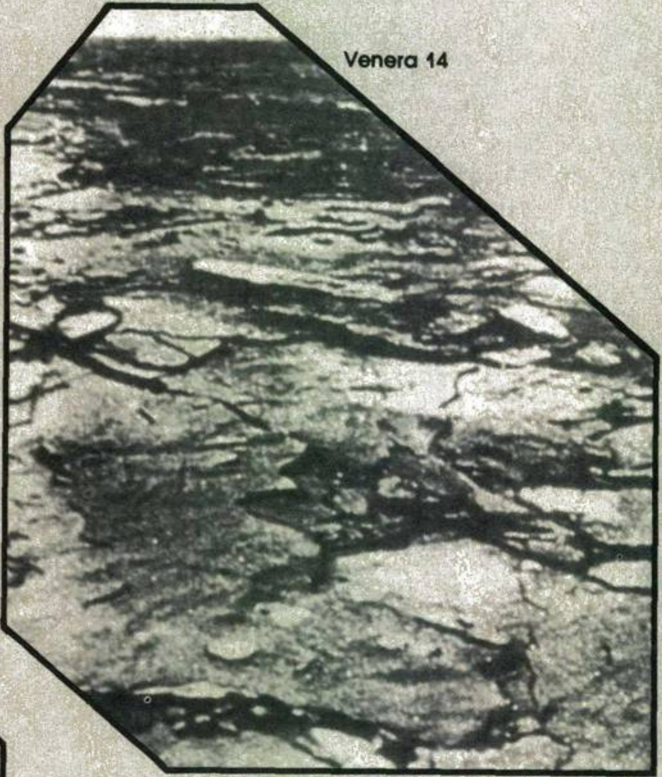
The 1978 probes surprised researchers by detecting lightning. But Venus' clouds aren't the type that should be able to produce it — what was going on? An important clue came from data taken by NASA's Pioneer Venus orbiter. It showed lightning happens mainly over features suspected of being volcanos. Gas and dust spewed out by terrestrial volcanos can provide intense lightning displays, so the reasoning is the active venusian volcanos cause the lightning. Veneras 13 and 14 found no lightning in the high clouds but only near the surface, another confirmation of the volcano hypothesis, and Venera 13, which landed on the flanks of a volcanic area, recorded more lightning than its sister craft 1000 kilometers away.


Venera 13

The Venera probes were designed to survive the heat for just 32 minutes. It was a race against time. Each picture — four in all, two sides of the probe in two colors — required eight minutes to take and transmit. Drilling a sample out of the ground required 12 minutes. Things worked so well that both probes had extra time to collect data: Venera 13 lasted 127 minutes and Venera 14 lasted 57 minutes.

Soviet scientists had targeted the craft to land in two different areas. Venera 13 put down on a strip of rolling plains bounded by highlands to the west and a lowland region to the east. Venera 14 put down on the adjoining lowlands. Radar studies show that these terrain types cover most of the planet: rolling plains cover 65% of the surface and lowlands 27%.

At first glance, the photos from the two sites look alike — slab-like rocks covering a flat surface. A closer second look, though, reveals a major difference. Rocks cover Venera 14's entire location, but a cloddy soil covers much of Venera 13's location.


Venera 14

Venera 14's site looks like areas on Earth where fluid lava has spread across a plain. As the molten rock cooled, it cracked to form numerous plates of stone. Some geologists think the scene more closely resembles areas where hot volcanic ash has settled onto a plain, the particles have cemented together, and then cracked into slabs. Either way, the individual layers making up the rocks are thin. Soviet scientists have counted up to six strata in some slabs.

Whatever created these scenes may have occurred — in geological terms — quite recently. Weathering will gradually crumble any rock, but Venera 14's pictures show none of the fine material that would result. Unless winds have removed all the pieces, the stones at the Venera 14 site are too recently formed to have begun breaking down.

Venera 13's landing site seems to lie at the other end of the weathering scale. Loose soil and dust blanket most of the ground around the probe. On our world, soil and dust result from erosion and chemical reactions that slowly break apart rock. On Venus, terrestrial-style erosion is unlikely because there's no liquid water at its high surface temperatures and the winds move slowly.

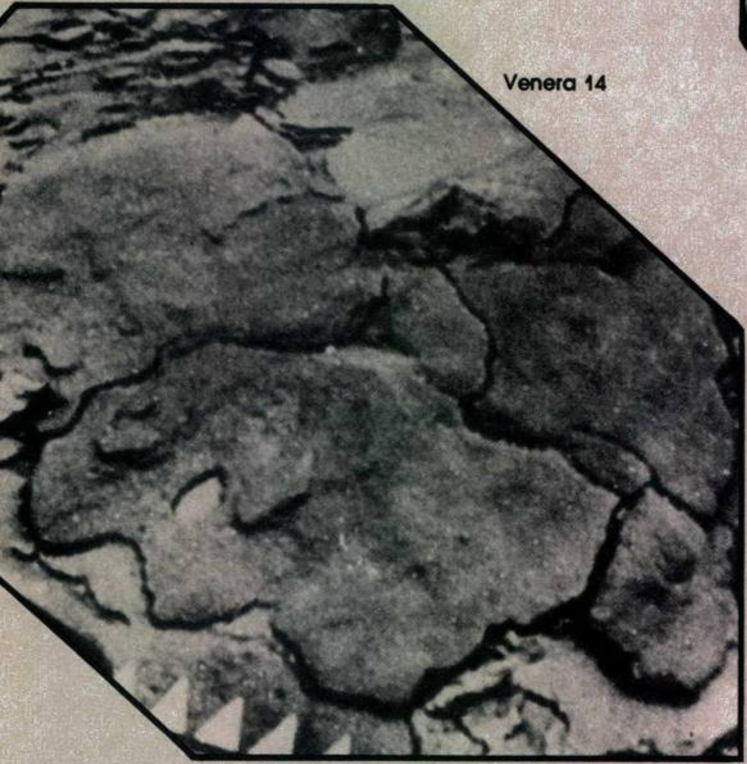
Given its high temperature and pressure, chemical weathering on Venus should be efficient and destructive. The tiny percentage of water vapor in the lower atmosphere would react with the rocks as would any of several other gases. The brown tints in the color photographs hint that the surface material has become highly oxidized.

The few rocks at the Venera 13 site could even result from chemical activity, soils cemented together into sedimentary rocks. And, like many terrestrial sediments, they don't appear to have much strength. One of the photographs suggests that the touchdown shattered a slab stone. Some researchers think that the landing may have produced the "soil" around the probe by breaking up sediments. In contrast, Venera 14's touchdown apparently chipped off just a few pieces of rock.

Combining the new data with the old Venera 9 and 10 photographs, geologists now have seen four spots on the surface of Venus. Only one place, the Venera 9 site, shows the blocky rocks and boulders common on the Moon and Mars. Venera 10 returned a scene looking much like the Venera 13 site. Meteor impacts on all the planets have strewn blocky debris across their surfaces. Venus, like the Earth, but unlike the Moon and Mars, must be able to weather away or cover the resulting debris.

Veneras 13 and 14 found other similarities with our world. After drilling and bringing soil and rock inside themselves, the Venera landers bombarded these samples with X-rays. The atoms in the specimens in turn emitted their own X-rays. Soviet scientists measured their energy and intensity to learn the abundances of certain key elements in the samples. The next step was to search for terrestrial material of similar composition.

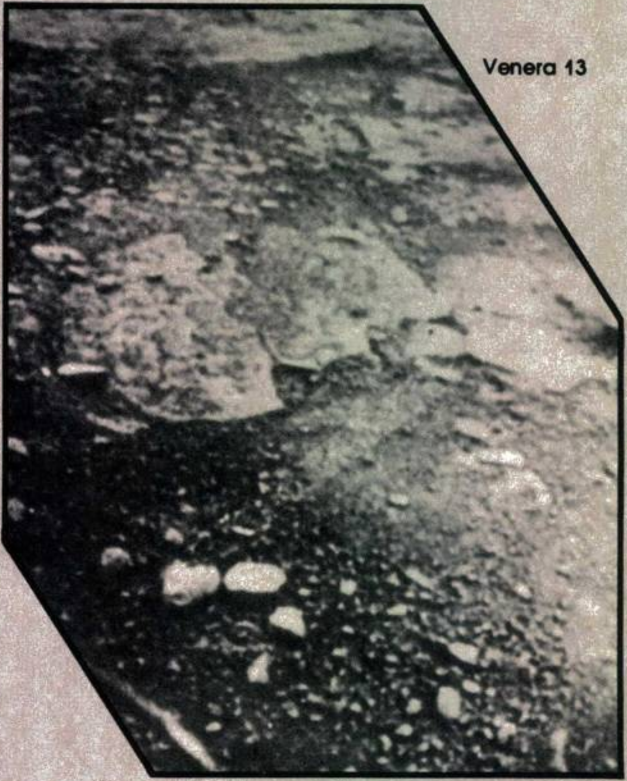
Matching up the Venera 14 sample was simple. It resembles a tholeiitic basalt, a common type of volcanic rock covering the Earth's sea floors and the Moon's mare basins. This particular finding hints that the lowlands of Venus may have the same origin as the lowlands on the other terrestrial worlds. The apparent youth of the rock suggests that the process that made it is still active on Venus, as it is on our world.



Venera 13 sampled a type of basalt rich in leucite, a rock fairly rare on the Earth. It appears two places on Earth, in volcanos in Wyoming and Montana and in the West African rift zone. This wasn't the type of rock geologists had expected.

The terrestrial worlds show a common pattern in their surface compositions. Rocks of the granite family tend to form the ancient highlands. Rocks of the basaltic family tend to form the younger lowlands and volcanic areas. According to this scheme, a probe landing on Venus' rolling plains, as Venera 13 did, should find granites.

Venera 8, which also landed on the rolling plains, found rocks with a high potassium content. At the time, geologists believed it had analyzed some form of granite. Venera 13's results will force researchers to rethink that conclusion. Leucite-rich basalts, unlike other basalts, have a high potassium content. Venera 8's relatively crude method of analyzing the soil would have produced similar readings on leucitic or granitic rock.



Finding non-granitic rock on the rolling plains could mean several things. Something, such as lava from a volcano, could cover the expected granites. Several researchers, in fact, suspect the soil at Venera 13's site came from the volcanic region to the west and may not be typical of the material covering the rolling plains. Or the rolling plains may not be equivalent to the highlands of other worlds. Or Venus may have formed differently.

"These landers improve our resolution of Venus 10,000 times over what radar studies have shown so far," says Harold Masursky of the U.S. Geological Survey. "The coverage is limited to their landing areas, but they can make detailed measurements of those sites. The results can strengthen the conclusions we draw from the radar maps, or they can force us to modify those conclusions."

Unfortunately, it's hard to extend the lander data to explain the entire surface of Venus. Masursky, for example, believes that venusian geology is more like lunar and martian geology than terrestrial, that is, that geologic activity largely confines itself to volcanic eruptions. Jim Head and Jim Garvin of Brown University are not willing to rule out the opposite view. They speculate that Venus' crust may be broken into plates which, like the Earth's, can move around. The Venera results can be fit into either view.

All geologists agree that what's needed is a mission to map Venus in detail, a mission to answer the basic questions about the surface. The data from the Venera landers will become even more valuable because researchers can relate them to specific surface features on the surface instead of broad terrain types.

By Van R. Kane

dynamically renewing them from below. The first alternative relies on active plate tectonics on Venus; the second requires cooling of the near-surface. The third suggests plate motions are not important on Venus, and provides an alternate explanation for the topography we see.

What is hot spot volcanism? As it cools, the molten rock of a planetary interior slowly rolls over — warm plumes of molten rock rise toward the surface, cool, then slowly sink back to the interior. Near the surface, the places that happen to be above a hot rising plume will be hotter than other places on the planet. If molten material from beneath weakens the crust, lava from the interior may pour through.

Depending on how long-lived plumes are, a hot spot may remain hot for billions of years. On the surface above a hot spot, we see volcanos and other geological signs of escaping internal heat. Terrestrial hot spots remain in one place for a long time, but the crustal plates slide around the surface. A hot spot, therefore, often leaves a string of volcanos or volcanic islands on a plate that has passed over it.

On Venus, the crust may not have mobile plates. A hot spot could continue to act in the same place for billions of years without anything to interrupt it or smear it into a chain of small volcanos. Beta and Aphrodite seem to be gigantic volcanic regions that are active today. And plates? For the most part, Venus doesn't seem to have them.

Weathering

On Earth, water is the major agent of mechanical and chemical weathering. Water dissolves minerals. Water expands when it freezes, enlarging cracks in rock, and its inclusion in the molecular structure of rocks weakens them. By itself, the lack of water on Venus would significantly slow nearly all the processes of erosion and weathering on Venus. However, the high temperatures and pressures at the bottom of the atmosphere suggest that chemical reaction rates, and hence weathering, could be accelerated.

Data from Pioneer Venus and the Venera landers indicate winds near the venusian surface range from one to two meters per second — certainly enough to transport dust and fine sand. These winds can most easily move particles about 80 micrometers in diameter, or a few thousandths of an inch, but the thick air subdues both *saltation*, movement by bouncing across the surface, and abrasion, caused by impacts of particles moved by wind. These processes are important in the thin atmosphere of Mars.

The Interior of Venus

We know very little about the inside of Venus. Probably the most critical gap in our knowledge comes from the lack of seismic data — but the conditions at the surface make putting a long-lived seismograph on the surface a difficult job indeed. Yet by making a few assumptions, we can deduce a surprising amount from a number as basic as the average density of the planet. We now know this accurately since we have determined both the mass and radius quite accurately from the orbits of spacecraft.

If Venus were literally a twin of Earth, then its density is about 2% smaller than it should be. This has usually been interpreted as the consequence of more oxidized iron, a low density material, in the venusian interior. Two processes could have influenced the iron content in different ways. Venus was heated less than Earth by infalling bodies because of its lower mass, but since its orbit is 30% closer to the Sun, the infalling material would have been hotter. Obscure processes in the solar nebula just prior to the origin of Venus might also have reduced the amount of iron Venus received.

Another important clue to the interior of a planet is its magnetic field — and Venus has essentially none. Global magnetism is associated with the circulation of a molten iron or electrically conductive core, so the lack of a field suggests that either Venus is temporarily undergoing a near-zero field condition during a polarity reversal, or that something very odd is occurring in the planet's interior.

Earth's magnetic field has capriciously reversed its polarity many times, typically every million years, each time passing through a time of near-zero magnetic field of a few thousand years duration. If Venus were Earth-like inside, however, the odds are about 1000 to 1 against our just happening to first explore Venus at a time when Venus is undergoing a polarity reversal.

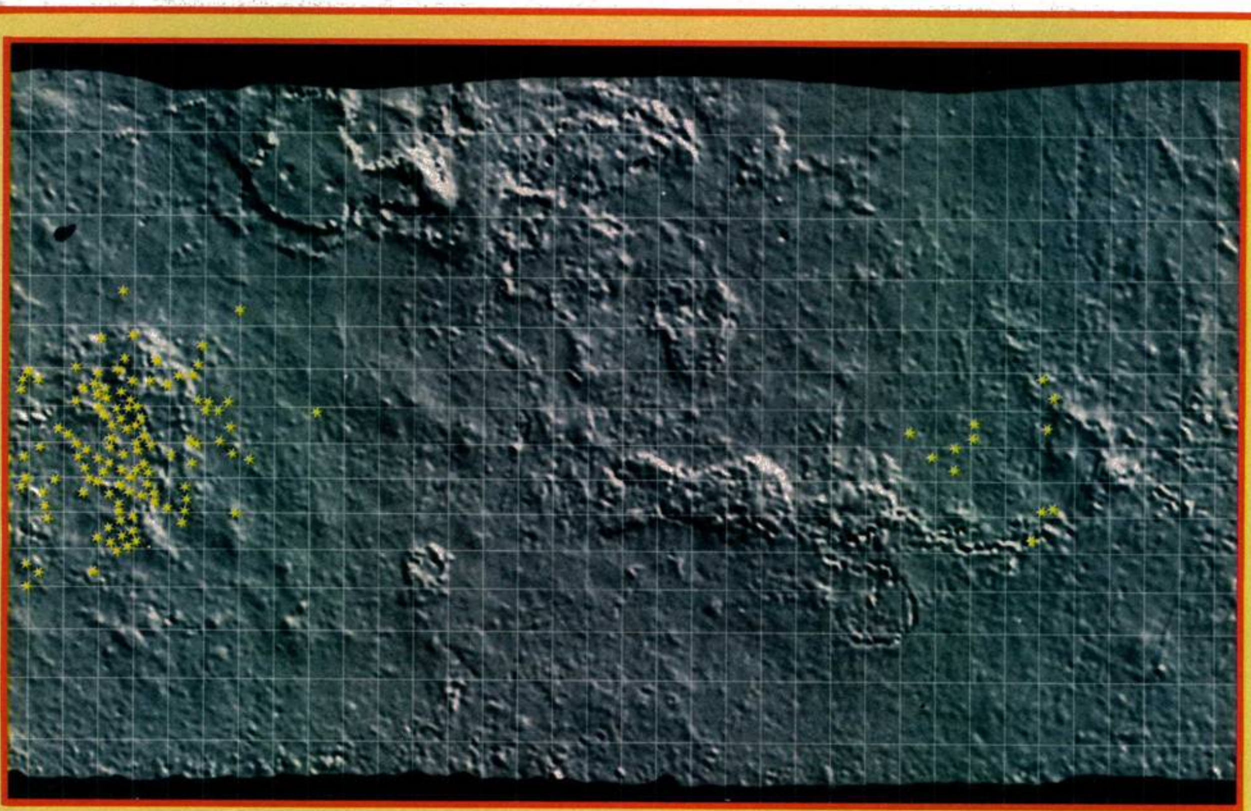
If we make the assumption, by analogy with Earth, that Venus has a partially molten iron core, then lack of an energy source to maintain the complex sloshing necessary to produce a magnetic field could explain Venus' oddball magnetic state. For Earth, one suggestion is that the core is powered by the freezing of molten iron and the gravitational migration of this solid to Earth's center. If Venus' interior were hotter than Earth's, the central temperatures could make it impossible for iron to solidify — shutting off this mechanism, and magnetism for Venus.

Theorists also contend that rotation is important in driving circulation in the core. The plodding spin rate of Venus may further contribute to lack of magnetism. Just to keep things in perspective, remember that we don't even have any direct evidence for the existence of a core of molten iron in Venus. Gravity data suggest that either the core-mantle boundary is very smooth or Venus has no core at all! If bumps or roughness along the outer core-mantle boundary serve to energize the core motions, the prospects for venusian magnetism would fade still further.

A Tentative History of Venus

One of the major goals in studying a planet like Venus is to uncover why it is both like and unlike Earth. We have certain realities which any history of Venus must explain — the massive atmosphere, the disappearance of large ancient craters, the thick crust, the volcanic highland Beta, the chemical abundance patterns, the anomalous inert gases, the apparent lack of plate tectonics, the Earth-like "continent" Ishtar.

The evidence points toward a critical event in the



Venus

lightning map

Lightning on Venus concentrates in two regions, a dense grouping in and around Beta Regio and another area in the "scorpion's tail" of Aphrodite Terra. This map shows three years of low-frequency radio data from Pioneer Venus. Courtesy NASA/TRW.

history of Venus: a time when it super-heated. Since Earth never super-heated, why did Venus? What factors brought it on? The main differences seem to be temperature, timing, water, and carbon dioxide.

Since the rocks of the two planets are roughly the same, Venus and Earth have vented approximately the same quantity of gases over their whole evolution. But in Earth's history, the oceans removed carbon dioxide. Carbon dioxide is soluble in water, and once dissolved, it reacts chemically with rocks to form carbonate rocks: limestones and dolomites. If all carbonate rocks on Earth were converted back to carbon dioxide, Earth would have roughly 100 atmospheres of CO_2 — like Venus. Without its oceans, Earth would have become an oven like Venus.

Astronomers have long believed Venus was always too hot for liquid water to survive on the surface — but this may be wrong. Theoretical models of stellar evolution show that our Sun was about 30% cooler than it is now when the solar system was young. The lower solar luminosity, coupled with a relatively thin atmosphere still escaping from the interior, may have allowed Earth-like conditions for a time on Venus — complete with lakes or a shallow ocean.

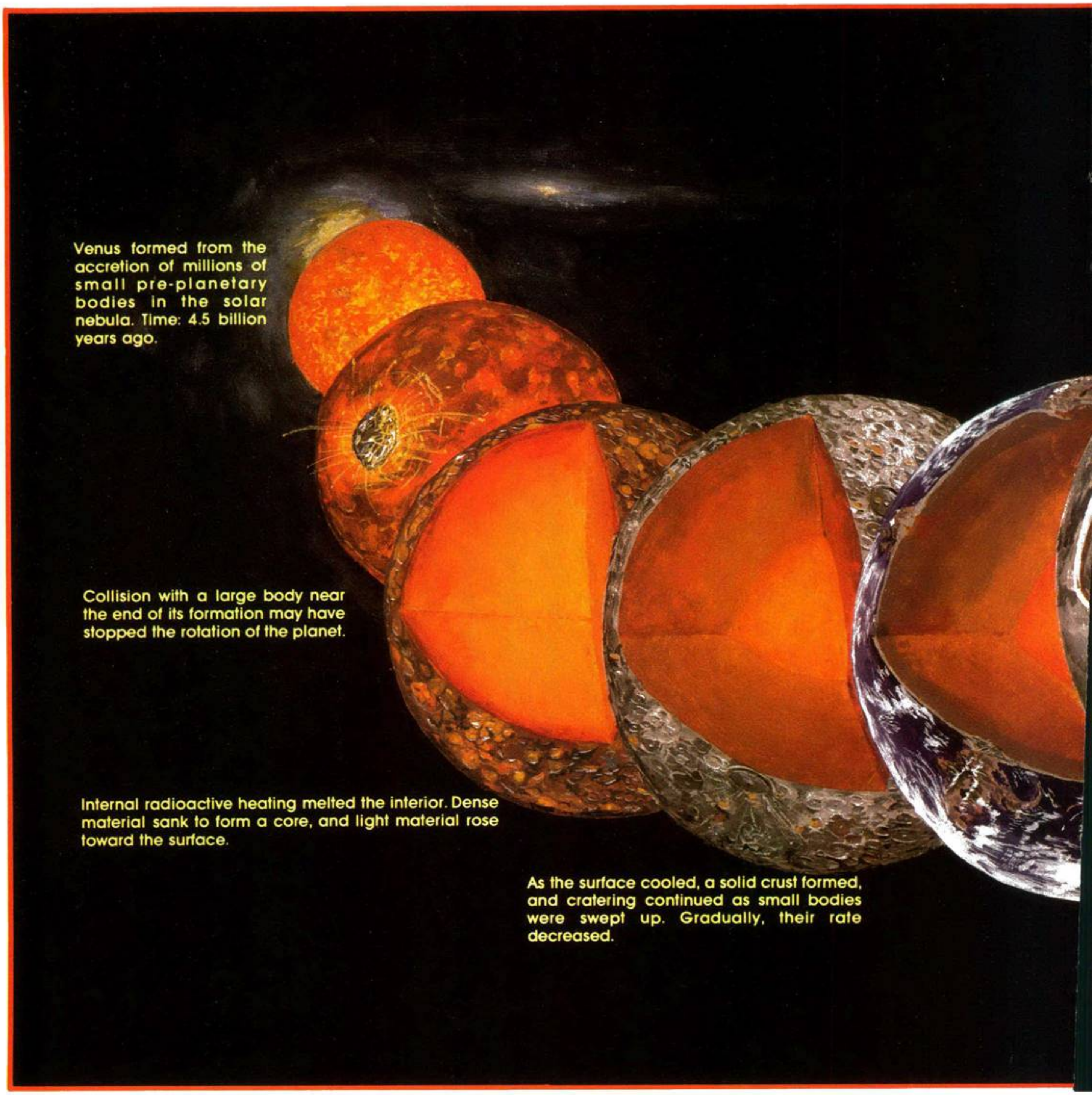
As the Sun's output increased and the atmosphere grew thicker, Venus warmed up. Higher temperatures forced water to evaporate, and increased water vapor in the atmosphere added to the steadily rising temperatures — until the greenhouse effect finally went out of control.

The temperature spiraled, water vapor high in the atmosphere dissociated, under intense ultraviolet solar radiation, into hydrogen and oxygen. The light hydrogen molecules escaped into space while the heavier oxygen atoms combined with carbon and the surface rocks of the planet.

Once it began losing its water, Venus was doomed. As carbon dioxide from volcanos entered the atmosphere of Venus, it stayed. Terrestrial volcanos vented CO_2 into the air too, but the oceans were able to remove it fast enough. Earth remained cool, while Venus got hot.

The best support for the "greenhouse catastrophe" comes from Pioneer Venus mass spectrometer measurements of the deuterium to hydrogen ratio on Venus. Venus has 100 times more deuterium atoms for each hydrogen atom than Earth. Since low molecular weight is crucial when gas escapes from a planet into space, the light hydrogen escaped during the destruction of water during the greenhouse catastrophe while the heavier deuterium remained. The new Venera images also show predominately brown "oxidized" terrain — presumably the chemical resting place for a vast quantity of left-behind oxygen.

A tentative summary of the major events in Venus' evolution includes the formation of the planet by the accretion of smaller bodies. At some point, Venus seems to have sustained a major impact which radically altered the planet's spin and delivered



Venus formed from the accretion of millions of small pre-planetary bodies in the solar nebula. Time: 4.5 billion years ago.

Collision with a large body near the end of its formation may have stopped the rotation of the planet.

Internal radioactive heating melted the interior. Dense material sank to form a core, and light material rose toward the surface.

As the surface cooled, a solid crust formed, and cratering continued as small bodies were swept up. Gradually, their rate decreased.

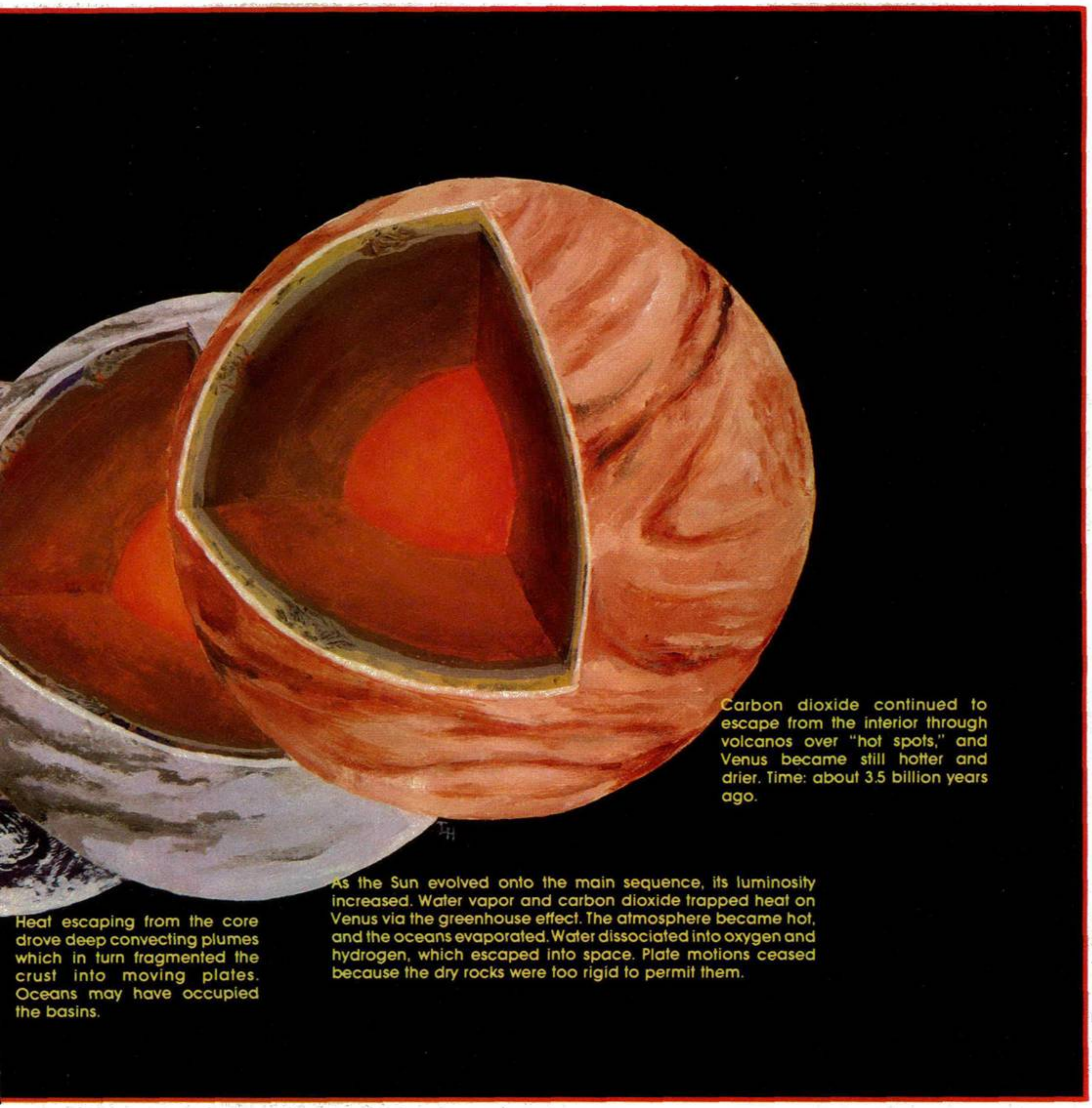
Venus

a complex history

certain anomalously abundant inert substances. Although Earth captured its Moon in a stable orbit, perhaps a similar object hit Venus, virtually halting its spin.

As proto-Venus heated from the impacting bodies and the decay of radioactive elements, the interior melted and dense materials — iron and nickel — sank to the center. Heating also drove volatile materials outward and a primitive atmosphere formed. As time went by and the impacts stopped, Venus finally began cooling, a solid crust formed, and active Earth-like plate tectonics began building continents, possibly Ishtar, and lowland basins on its surface. Oceans may have even filled those basins.

Then came the super-heating catastrophe. The greenhouse effect, working in conjunction with the rising solar output, destabilized water on Venus. In a few hundred million years, the oceans evaporated, water vapor rose and circulated through the atmosphere, sunlight broke H_2O into hydrogen and oxygen, and the hydrogen escaped. The less water Venus had, the more rapidly the carbon dioxide level



Heat escaping from the core drove deep convecting plumes which in turn fragmented the crust into moving plates. Oceans may have occupied the basins.

As the Sun evolved onto the main sequence, its luminosity increased. Water vapor and carbon dioxide trapped heat on Venus via the greenhouse effect. The atmosphere became hot, and the oceans evaporated. Water dissociated into oxygen and hydrogen, which escaped into space. Plate motions ceased because the dry rocks were too rigid to permit them.

Carbon dioxide continued to escape from the interior through volcanos over "hot spots," and Venus became still hotter and drier. Time: about 3.5 billion years ago.

painting by Thomas L. Hunt

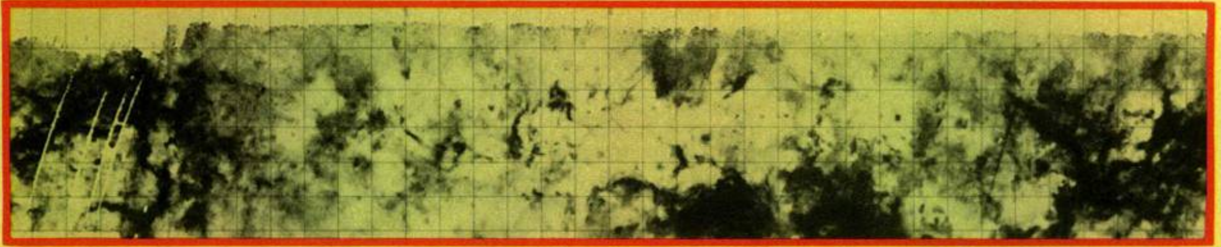
rose.

Then Venus dried out — first the upper layers of rock, then the whole asthenosphere. Crustal rocks became lighter and more rigid. As the temperature rose still higher, basalt no longer transformed into eclogite under pressure, and finally plate tectonics came to a stop. With the cessation of plate motion, Venus switched tectonic style to its current hot spot volcanism and building of massive volcanic highlands such as Beta and Aphrodite.

During the pleasant early phase in its history, did life develop — or has Venus always been abiotic? One hint comes from the surprisingly large number of complex organic substances strewn through interstellar space. If these were introduced to Venus during its cool, wet phase billions of years ago, perhaps the planet could have supported life. Organic materials could have reached Venus by impacting comets, a mechanism suggested by embarrassed cosmochemists to account for the sulfur on a planet that should have none according to the best models of solar nebula evolution. But the time would have been brief, on a planet named for the Goddess of Love, before life was fried during the greenhouse catastrophe.

The Lessons of Venus

What have humans learned about planets in general from Venus? We've readjusted our thinking about our place in the solar system. Planetary radius and mass have been generally believed to be of prime



Pioneer Venus radar data has been invaluable in our efforts to learn about the hidden surface of Venus. Without higher resolution, without the ability to distinguish finer details, tantalizing glimpses of the geology of this once Earth-like world will remain all we have. NASA/Ames ORAD data.

Venus

a model for Earth

importance in directing the evolution of large rocky bodies. Size determines how heat energy is created, stored, transported, and ultimately lost. It also determines the rate of loss of important atmospheric gases into space.

However, the pivotal difference between Venus and Earth seems to be not mass, but solar distance. Solar distance affects the initial temperature, among other things. On Venus, the slightly higher temperatures hindered the accumulation of large liquid water reservoirs on the surface which might have headed off the massive build-up of CO_2 and the resultant greenhouse catastrophe. Prior to the destabilization of water, Venus and Earth may have indeed been twins.

This scenario affects our notion of how often life gains a foothold in the universe. The path to habitability may be far narrower than we used to think. Earth might have become, with a slightly different orbit, a hot Venus-like planet or a deep-frozen world like Mars.

It also makes us wonder about how stable the climate of Earth really is. By burning bio and fossil-fuels, humans have increased the CO_2 content of Earth's atmosphere by 15% — even with the oceans working to absorb it. How much more CO_2 can we pump into the atmosphere before we unbalance the climate of Earth?

Our tantalizingly fuzzy radar glimpses at the geology and geography of Venus have raised questions that now beg for answers. Did Venus once have oceans? Are the circular structures impact craters? Are the rolling plains ancient? Does Venus bear remnants of past plate tectonic processes in Ishtar and the Maxwell Montes? Does Venus have an Earth-like interior complete with a core of iron? When did Venus become the second hottest object in the solar system?

These questions can be greatly illuminated, if not answered completely, by a more detailed picture of the surface. We need imagery that can differentiate "hot spot" volcanos from folded mountains, impact craters from volcanic calderas, and faults from other linear features. How long will we have to wait before NASA gets the go-ahead to send a radar-imaging spacecraft to orbit Venus?

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Bruce Cordell is an assistant professor of geophysics at California State College, Bakersfield, where he teaches astronomy, geology, and geophysics. His research interests include overlapping areas of planetary science and geophysics. Many of the scientific findings in this article were announced or discussed at the International Conference on the Venus Environment held late last year in Palo Alto.

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ASTRONOMY FORUM

Bruce Murray Interview

Bruce Murray resigned as director of Caltech's Jet Propulsion Laboratory on June 30, 1982. He held the post for six years and had led JPL's fight to save a number of space exploration programs that budget cuts threatened to terminate. Along with Carl Sagan, he formed the Planetary Society. He discusses his future plans here in a telephone interview, and gives us an inside look at NASA, the government, and the future of our planetary exploration program.

ASTRO: If we could go back into history a little bit, how did you first get involved with planetary science? I know you're a geologist.

BM: Right. Let me give you some dates. I left MIT in October of 1955. I went to work for an oil company for what I thought was going to be a brief time, because I had an Air Force tour to serve, but I worked for them almost three years. So I started my Air Force tour then, in 1958 at the Air Force Cambridge Research Lab. Of course, 1958 was Sputnik and Explorer, the first U.S. satellite — exploration was just beginning.

The typical kind of problem I worked on was how to use satellites for gathering gravity and geodetic data for national security purposes. The work exposed me to the fact that there was a developing space age — otherwise I would have been looking down into the ground for oil instead of up to the stars. I also had to learn some astronomy, which was something I didn't know much about.

I decided the opportunity to actually explore the planets was close at hand, so I wrote to Caltech cold saying, "Here I am. I'm a geologist interested in astronomy and planets, and I'd like to work at JPL. Is there some opportunity to get started?"

The letter ended up in the hands of Harrison Brown, who was a leading geochemist for meteorites, and one of the first people at Caltech to see the new opportunities with NASA.

At Caltech I became involved with the experiment team that became the first Mars program, Mariner 4 — called Mariner C in the beginning. It was a very exciting period.

In July 1965, when Mariner 4 went by Mars, I was suddenly in the direct close-up observation business. Then came Mariner 6 and 7 in 1969, and then Mariner 9, which was the first Mars orbiter.

In the meantime I'd spun off and become the team leader for Mariner 10 to Venus and Mercury. It was launched in '73 and encountered Venus and Mercury in '74 and then re-encountered Mercury in '74. I had a very vigorous buildup in the space photography/planetary photography area. At the same time we were in the midst of some exciting infrared work on the ground.

In 1965 while Mariner 4 was encountering Mars, I had 200-inch telescope time — twilight time, which was all they gave us then. I chartered a plane and flew back and forth from Caltech to Mt. Palomar with cars at both ends. I observed Mercury, trying to get the temperatures of the dark side, and then would fly back to look at the data processing of the early pictures. It was a pretty heady time — the best of both worlds.

But by 1967 it was clear to me that I needed to make a choice; I decided to maximize the space effort and voluntarily relinquish my responsibilities in the ground-based areas. In the fall of 1971, even though I had enough work to carry me through early 1975, I decided not to do any more flight projects. I would have been on four of them. I decided to change. This is all relevant, by the way, to stepping down from JPL, because I've changed fields many times. It's always been mostly because I wanted to, and I chose the time and place. Starting in July of 1975, I decided to take a sabbatical which eventually became a Guggenheim fellowship.

A week after I got the notice of the Guggenheim, in April of '75, Carol Brown, president of Caltech, called me and said, "I'd like you to be director of JPL."

ASTRO: So it wasn't your choice, it was just . . .

BM: Completely accidental. I said, "That's fine, but I still want to take my sabbatical." I had planned on 15 months, and we compromised with nine. At the time I came to JPL it was clear to all involved that my term was a five, renewable to ten, year period. This was April of 1976.

I believe strongly, for both the individual and the organization, that there should be a turnover, often on that time scale, of directors. And so I said that "five to ten with time off for good behavior" sounded like a logical choice. The time scale came out to be six and a quarter years — well within the range that I had planned all along.

The choice to do it *now* was governed by the environment outside JPL. We've had a tough go the last couple of years. I believe we've survived and we're on a good, positive track — somewhat adjusted in program content, but with the basic policies of the system still being implemented. From the point

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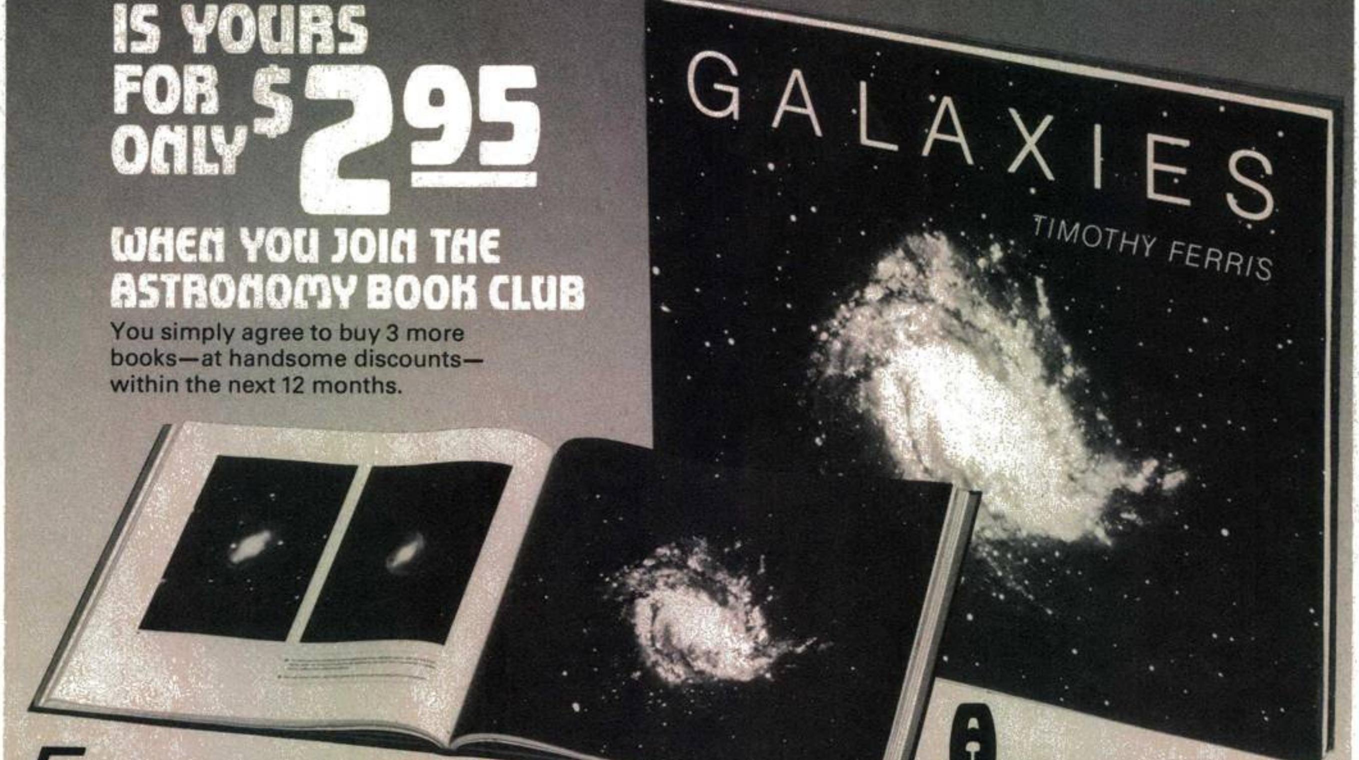

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of view of the Lab, it's a relatively quiet time for a change — at least compared to last year. We lost everything we could afford to lose, but we kept Galileo, the Deep Space Network, and Voyager. Those are not issues in my resignation, and in terms of carrying out the rather delicate surgery of extracting one director and bringing in another, I think this is a good time.

ASTRO: You weren't pressured in any way?

BM: No, no, absolutely not. Rather the reverse. Two years ago, I negotiated with Caltech president Goldberger, and he agreed in writing that I had a year's sabbatical whenever I stepped down, so that I could work on getting loose from JPL in a way that was best for JPL and not worry about what I was going to do in the future. I would have a chance to decompress from this job and sort out how I feel about things.

ASTRO: So when did you actually decide to resign?

BM: Well, I told you, I decided when I came. I made a decision it would be this year last July. I made the detailed decision on the timing in the fall. The decision has been governed entirely on the best time for JPL. The personal reconciliation that the planetary program has worked out more modestly than I hoped when I took over is what I expressed in the *Science* editorial. I think Apollo was an anomaly — we were lucky. It happened four decades too early, and Voyager and Viking and the rest were all spinoffs from that.

ASTRO: Do you feel frustration; do you feel that your time was wasted?

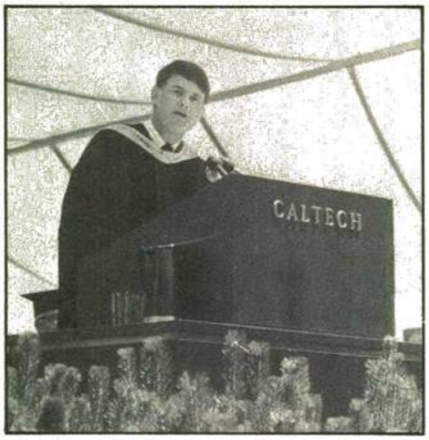
BM: No, no, no, no, no, not at all. I feel very fortunate for two things: one is to have hit the planetary exploration wave on the rapidly expanding portion of the curve, and to have ridden it out. The other is that I had an opportunity — which I did not seek — to be head of JPL, a unique position.

It could have been worse. There could be no Galileo. The Lab could be a shambles and the morale completely gone and people leaving. That hasn't happened. So if you ask what accomplishments I take personal satisfaction in, I'm glad I've been able to hold it together motivated by the same opportunities and dreams which it had despite times more difficult than anybody had imagined. Nobody predicted the kind of things we've run into.

ASTRO: If you could do it over again, would you change your strategy — would you go for small missions?

BM: I don't think we were destined to have this outcome. The civilian-based program grew and exploded because of Kennedy's decision on Apollo. The President of the United States said it was important to the country to explore the Moon, and he attached to that the mandate to explore deeper space. The person who succeeded him, Johnson, was the architect of that previous policy — when he was in the Senate he was the leader of the pro-space force. It's no accident that the Johnson Space Center is in Texas or that it bears his name. Both those presidents believed space was important politically, as well as technically, for the country.

Nixon — it's difficult to know. He did bite the bullet and make the shuttle decision. What he would have done beyond that I don't know, but Watergate happened and the second half of his presidency was ruined, any possibilities for presidential leadership vanished.



Ford had only one possible task — to restore the idea of the personal integrity of the President, which he did. But he really couldn't get much else done, and didn't. And then finally he was followed by Carter, who had an agenda of priorities much larger than his political base would let him deliver. Carter apparently felt that space wasn't good policy. He didn't have the Kennedy view. Although he personally was quite a fan, he wouldn't insert that into his political rhetoric or leadership. Reagan, so far, has been completely preoccupied with a budget cutting so that he has not been able to identify things that he might well support, although that could change.

We've had ten years, since June of '72 when the Watergate thing blew up, without any president able to say and demonstrate, "I believe that civil space is important to the country." *That* was a big problem — if there hadn't been ten years of presidents ignoring civil space, we could have certainly kept the planetary program going. And even without it, had there been a more courageous, more committed leadership within NASA, we could have kept it going.

This outcome was not preordained. It happened because a weakened presidency combined with a rather average, mediocre leadership within the executive branch. Inspiration at either level would have changed the outcome, and we would be going to Halley's Comet and doing a lot of other things we're not doing.

I want to emphasize that the fight we made *had* to happen. It was close, very close; we almost won in a couple of areas.

ASTRO: Which areas?

BM: The Halley's Comet mission. We really came close on that one. I think it would have made a big difference — Halley plus Galileo together with Voyager would have been a very exciting program. There was also strong support for the U.S. Solar-Polar spacecraft, but not quite strong enough — and they divided each other of course. But VOIR was always there — this bow wave pushed downstream — so the constituency was divided. If a few key decisions had gone the other way, I think we would have a much more aggressive program, which probably wouldn't have cost a hell of a lot more than the one we've got.

If we hadn't been fighting for Halley's, we probably would have lost Galileo. Because the tremendous show of support there did help — the show of support for JPL and what it was doing helped too.

ASTRO: Where do you see planetary exploration going now?

BM: I see it becoming more international, especially in the inner solar system. We've already got good outer solar system exploration going with Voyager and Galileo; that will remain. In the inner solar system, the Soviets will continue to carry out their aggressive program on Venus, very systematically and successfully.

New missions to Mars, the Moon, comets, will either be smaller national efforts, like the Halley thing, or collaborations. My own personal hunch is that Mars will eventually become the focus of a new wave of energy and enthusiasm. I hope it will be more internationalized, but it will be exploration of Mars anticipating eventual manned adventure and travel to Mars.

ASTRO: What time frame?

BM: I think you'll see the beginning of that in the nineties and it'll go into the next century. I also wonder to what extent the utilitarian

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basis of the Moon will be exploited, but I can't tell a time scale on that one.

MacArthur said, "I shall return," when he left Bataan; *homo sapiens* will return to Mars, first in the form of robot rovers exploring the polar areas looking for climatic records that may be relevant for Earth's future as well as its past.

First they'll explore the planet, and then eventually focus on manned exploration in the next century. The Planetary Society can help by bringing people together and enlightening hundreds of thousands — maybe even millions — of people to the possibility. Exploration of Mars is a long-term endeavor that has to be an international effort. I think by getting people, in the U.S. and throughout the world, talking to each other about it, recognizing their common interest, then you'll help maintain and gradually build a constituency for the future.

ASTRO: You went into some detail in your State of the Lab Address about where JPL is going. Do you have anything you'd like to add to that?

BM: I guess just the following, getting back to how I feel upon leaving: Obviously, this is not the future I had envisioned in 1976. But it is the best future JPL's going to have. So I feel very good about being part of the process that negotiated the Laboratory through some pretty tricky rapids.

The fact that the future isn't as glorious in the space exploration sense is one we imagined before, though any more extrapolation into the 80s is irrelevant. If JPL looked like they were throwing in the towel, then that would lead other people to do so. We have always made space exploration our highest priority. It still is, in the sense that our major effort is in that direction, although our commitments to the Defense Department are deadly serious: not a second-priority role, a first-priority role.

But that mix, two-thirds NASA and one-third Department of Defense, is reasonable and desirable. We'll be working closely with the Air Force space division and the Army research and devlopment teams, but I feel good about that. JPL is going to lead the United States, and therefore the world, in space exploration.

I feel satisfied that I've achieved something that might not have happened if somebody hadn't intervened. So this is to put to rest the idea, "No, I don't like that," and that's why I'm getting out. I would have gotten out no matter what. I'm ready for a change; it wouldn't have been good for this organization if I stayed here much longer.

ASTRO: What things other than working at the Planetary Society do you plan to do?

BM: I have some personal research of various kinds I'd like to spend a little time on. I have some writing that I'm committed to. These are backlogs of things that I've wanted to do but I haven't, so they're first.

I *will* continue my involvement, probably as part of the advisory structure to NASA. I have other things I'd like to try, but the first job is to get loose from JPL, see how I feel, probe here and there, and then put together a package of activities that I find rewarding.

ASTRO: So you haven't decided what your next step is?

BM: No, and I'm in no hurry to do so.

— *Van R. Kane*
San Jose, California

Why We Need a Space Tug

"What's next?" in space now that the space shuttle is flying? NASA's engineers labored over the shuttle program for nearly a decade, slighting other branches of our space agency and garnering unfavorable headlines each time an engine blew up on the test stand or a heat shield tile fell off. Now, NASA's top brass is basking in the limelight, and public opinion polls show that a majority of Americans favor the space program — a reversal of the situation in the 70s. Heady stuff after years of bad press.

So now that the shuttle is proving itself, what will we do with it? One obvious answer is to build a space station — after all, the shuttle is tailor-made for space station construction and re-supply missions. In fact, the Space Transportation System (NASA's official name for the shuttle) originally consisted of the shuttle, a space station, and a reusable orbital transfer vehicle (OTV) or "Space Tug."

Studies are already underway at NASA's Johnson Space Center in an effort to define the station. The concept, called the Space Operations Center (SOC), is a modular structure designed to be carried up piecemeal and assembled in orbit. As the name implies, SOC is not a research station *a la* Skylab since the crew will have operational duties of retrieving and maintaining free-flying satellites.

There is little doubt that the coming industrialization of space requires a manned orbital station. And, by the end of the 1980s, anticipated traffic to and from synchronous orbit will be so heavy that we'll need an SOC just to maintain communications satellites in the high orbits and tend the Space Telescope and Earth resources satellites in the lower orbits. The price tag for the SOC: $10 billion.

But is it politically feasible for the President and the Congress to commit the nation to a multi-billion project now? During these times of cutbacks in federal spending, especially when social programs are being drastically cut, it's not likely!

A more politically prudent path to follow, more appealing to the budget-conscious policy makers in Washington who make or break NASA's budget, is not only less expensive, but also would fill a pressing need by bringing the space program to the point where a space station really would be the next logical step. That course is to begin work on the Space Tug, the third element of the original space transportation system.

As originally planned, the tug would have developed concurrently with the shuttle. It was to have acted as an upper stage for the shuttle, taking payloads out to 23,000-mile high synchronous orbit and guiding planetary probes on their escape trajectories. Since NASA's projections show that 60% of prospective shuttle payloads need to reach synchronous orbit or beyond, a tug would be in demand during the '80s.

But due to the stringent budget constraints in the early 1970s, NASA decided to defer OTV, the tug's acronym, until peak funding for shuttle development had passed. This recommendation came despite an American Institute of Aeronautics and Astronautics study that concluded that expendable upper stages could be used initially but that a fully reusable OTV would be needed eventually.

Commenting on the OTV's cancellation, Dr. Bert Edelson, director of Comsat Labs, lamented: "If anything keeps the shuttle from being a commercial success, it will be the lack of a good tug." So at a time when traffic to and from synchronous orbit is expected to increase 10 to 30 times, NASA is courting disaster in backing the SOC rather than developing the OTV.

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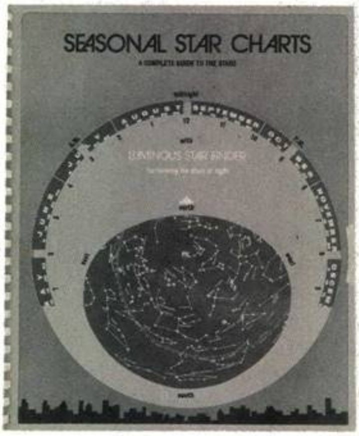

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hydrogen and sporting two RL-10 engines, the Centaur has been sending U.S. spacecraft to Earth orbit, the Moon, and the planets since its first flight in 1962. Its proven capabilities and its hydrogen fuel — the lightest and most powerful fuel in use — makes Centaur perfect for flying comsats to synchronous orbit. In addition, a Centaur OTV would dovetail neatly with NASA's planetary program — the Galileo mission to Jupiter was designed to be launched aboard a Centaur upper stage. But Centaur has been cut.

The Centaur OTV was vital to the shuttle's commercial success — especially considering the bulk of the shuttle's customers will pay big bucks to get their comsats up to synchronous orbit. The need is even more acute since the Inertial Upper Stage, now NASA's choice for an interim tug, is behind schedule, over budget, and not as powerful as planned.

But assuming that NASA decides to back an effective OTV as its next major project, the U.S. civilian space program would lead naturally toward the SOC as the next focus for activity in space. The progression could follow these lines: wide-body Centaurs launched aboard a shuttle will at first operate as they traditionally have, as one-shot throw-aways.

A reusable Centaur will become practical only with an orbiting parking place to leave the 35,000 pound rocket until its next mission. Why relaunch all that weight when the Centaur could be left in a parking orbit? The Centaur would require electrical power and stabilization so that a shuttle could safely approach and dock with it. The Power System Platform (PSP), under study at the Marshall Space Flight Center, would provide solar panels for power generation and three-axis stabilization. A shuttle mission with a comsat aboard would rendezvous and dock with the PSP and Centaur OTV, and the shuttle would bring fuel to fuel the Centaur along with the comsat. After mating, the Centaur would carry the comsat out to synchronous orbit then return to the PSP until it was needed again.

Carrying highly explosive liquid hydrogen in the shuttle cargo bay is likely to give even the most experienced astronaut pause, so the next step is to add facilities necessary to convert the "parking lot" into "gas station." The addition of one or two PSPs and a platform to which an empty shuttle external tank is attached would enable the shuttle to deliver the volatile hydrogen and oxygen in the form of water — a much safer proposition all the way around.

Water would round out the shuttle's payload on flights where the lift capability was not used. After it was broken down by electrolysis or direct reduction into its constituent hydrogen and oxygen and stored on the platform, this gas station in the sky could serve the needs of a whole fleet of tugs.

At this point, in the early '90s, the tug fleet would handle heavy traffic to and from synchronous orbit. Simply by adding habitation modules — like those now under study for SOC — a crew of astronauts and scientists would become a permanent manned presence in space.

By building the SOC first and finding uses for it later, NASA will arm its opponents — and we'll hear powerful arguments for cutting space from the budget. But if NASA bides its time during this decade — letting Spacelab experiments and the growing comsat market demonstrate that there are indeed good reasons to live and work in space — the program will proceed to the point where an SOC will fill definite needs. And, very likely, it will turn a profit at the same time.

If NASA decides to gamble on the SOC at a time when the Administration is embarrassed by federal spending, the agency risks a repeat of the criticism that nearly wrecked it in the early '70s. NASA's post-Apollo goals, primarily a manned Mars mission, were politically unsupportable. Let's hope that this time NASA explores the political ramifications of a new program as carefully as it studies its technological feasibility.

Thomas J. Frieling
Bainbridge, Georgia

Mr. Frieling is the executive director of the Campaign for Space Political Action Committee.

Alone But Not Lonely

Ben Mayer is best known for his PROBLICOM nova search program, but he has been active in astrophotography for many years, and is the recipient of the Astronomical Society of the Pacific's 1982 Amateur Achievement Award for outstanding contributions to the field of astronomy.

ASTRO: How did your interest in astronomy develop?

Mayer: It takes a certain measure of brazen honesty to admit that you bought your first telescope because you lived on a hill and could see a dozen swimming pools. But that is, in fact, the unvarnished truth — I was a professional voyeur before I became an amateur astronomer.

By late October I couldn't see any more girls beside swimming pools so I trained my telescope on the stars. I looked at the Orion Nebula, one of the few objects I knew in the sky. I was also familiar with the star Vega in Lyra. These were things I'd learned from my father as a child in Germany. The Orion Nebula kept moving out of my field of view. I realized that if I plugged in the electric motor of my 8-inch Celestron, the nebula would stop moving. I quickly became aware that the motor compensates for the motion of the Earth.

The Orion Nebula held my interest; it looked so enigmatic, so mystical. I attached a camera to the telescope to photograph it as the Celestron advertisements suggested — every star on the photo had eight legs, like some sort of a lady bug. Still, my first photo of M-42 was the most important, Earth-shaking and beautiful astrophotograph that had ever been taken, even though today I know how poor it was.

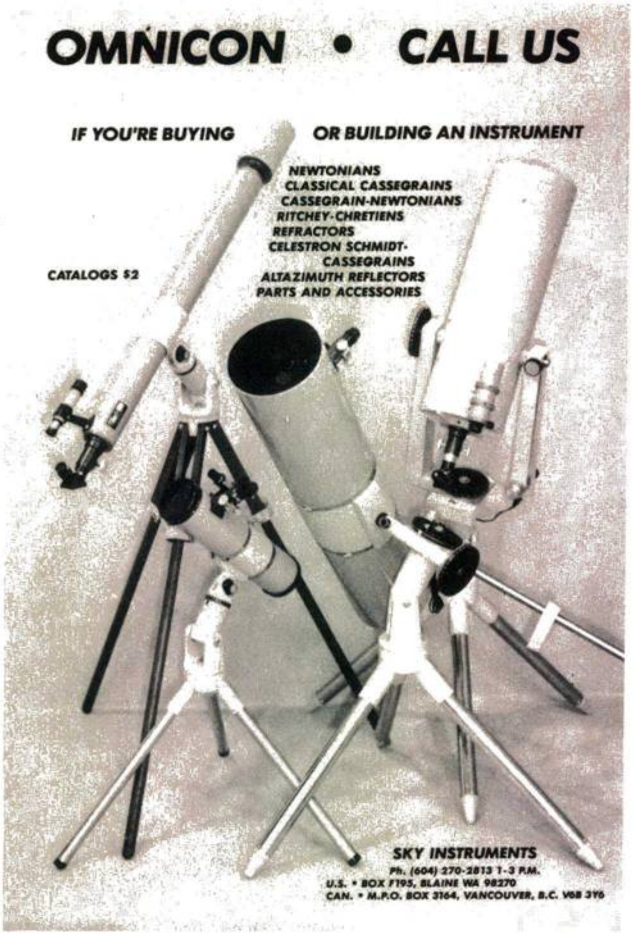
ASTRO: You seem to have a great love for sophisticated and exotic equipment — your very first astronomical article was about ARCTU.

Mayer: ARCTU is an acronym. I learned about acronyms from NASA where they have one for everything. ARCTU stands for Automatic Recording Celestial Tracking Unit, a big mouthful to describe a 35mm Pentax camera with a lawn sprinkler timer attached so it would take photographs of the sky at 20-minute intervals while I slept. I loved astrophotography but I also needed to sleep — I wanted to do both at the same time. I devised ARCTU to capture meteors, and even caught a few.

They were very dramatic but of very little scientific value unless someone else also took photos from a different location to permit you to establish the meteor's position by triangulation.

I never found someone to triangulate with, so I gave up meteor astrophotography — but not before I photographed Nova Cygni 1975 while looking for meteors. I took 14 prediscovery photos of a nova actually exploding, growing in brightness.

The point I want to make — and it's very important to me — is that costly and esoteric equipment doesn't do things by itself. I have a simple camera and I'm willing to invest lots of my time. Time is free.



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Time and discipline . . . I'd like to think that I have discipline, too. But anyone with a 35-mm camera and discipline can do very important and meaningful work in astronomy.

ASTRO: When you developed the PROBLICOM Sky Survey, what did you see as the ultimate purpose of this time-consuming effort?

Mayer: That brings us back to time and discipline, the two ingredients that amateurs possess in abundance. Mind you, "amateur" stems from the word *amor* meaning love. These two ingredients, plus a certain measure of passion for his hobby, are what the amateur should be willing to dedicate to the stars.

When I started the PROjection BLInk COMparison program, I anticipated that people like myself would be willing to spend time photographing the sky. As long as you provide the professional fraternity with data, they can do the rest. PROBLICOM is a program heavily dependent on the willingness of amateurs to spend time and shoot sky areas again and again to find novae or even comets. It's something that needs to be done year in and year out to make it important.

ASTRO: How is PROBLICOM as you see it today?

Mayer: The Program has yielded both encouragement and disappointment. It has brought me together with people that are devoted and committed to the belief that we can do important work. But it has also put me in contact with talkers, people who start on a high note and then, after I've invested time in them, just drop out.

In essence PROBLICOM winnows the doers from those who only give lip service. I guess it has to do with one's approach to life, whether you are dedicated or whether you are a dilettante. I forget about the disappointments — I must, or they upset me too much. I want to continue to work with those who share in my beliefs. We are, in a way, chasing rainbows, or in our case chasing novae and comets.

Leslie Peltier, a man who discovered a dozen comets, said: "If you want to find comets — keep looking." The same goes for novae — keep photographing. You must, however, do this with method and order. PROBLICOM is an endeavor for disciplined individuals only. All others need not apply.

ASTRO: Not so long ago, you photographed all the Messier objects in color. Tell us about this.

Mayer: I have the pleasure of being a friend of Dr. Hans Vehrenberg, a well-known German amateur astronomer. We speak in German, my native tongue. He told me that he was seized by a collector's passion when he started astrophotography. After taking one picture, he felt he had to take many pictures, and then the whole sky.

So it was with me. Once I had begun, I had to take all of the Messier objects, all 110. This was a demanding task, shooting each object in color with a cold camera, since the process is complex and fraught with problems.

And I started the photography during warm summer nights, little realizing that on the -4°F winter nights I would have to shovel snow before being able to use my telescope. Because of my collector's passion, also discipline, I did not beg off. I hung in there, stayed with it, and photographed the whole lot of them. The project took 18 months. Many objects took 40 to 120-minute exposures, and the first shot was not always the definitive one. Perhaps it takes the dedication of a madman to do such a thing.

ASTRO: Your ability to write interesting and readable articles is noteworthy. Does your approach to writing reflect special schooling?

Mayer: I was born in Germany; I did not speak a word of English until I was twelve. I find communication and language vital. It is a rare gift to speak more than one language; I do, and that takes a certain discipline too.

To use this language and spread the word of astronomy to people is my task in life today. I want to be a popularizer of astronomy. I would like to bring people to the stars or bring the stars to the people. I try to bring feeling to astronomy along with science. This is not a hobby, but a passion.

ASTRO: Tell us about a typical astronomical weekend.

Mayer: It needn't be a weekend anymore. I've prioritized my life. New Moon can happen at any time, on a Tuesday, for instance, and then I go to my observatory. I tell my clients that I cannot go to Mexico because the Moon is New. They know I don't make money when the Moon is New. I'm proud of that — I know my priorities.

I begin my night with the PROBLICOM photos. I may take as many as 108 sky areas — three 36-exposure rolls of Tri-X during one night. I begin at the end of the astronomical twilight shooting 10°x15° sky areas near the western horizon and slowly work eastward. This continues until the beginning of astronomical twilight before dawn. But photographing 108 frames is less than half of the task. It will require about 18 hours of blinking, two to three days of blinking pleasure, to search them for novae.

While these pictures are being taken with ARCTU, I'll also take 4-minute exposures — with the C-14 and the intensifier — of galaxies in search of supernovae. I plan a galaxy patrol in advance, selecting new targets to examine. All this is done in black-and-white.

I'm done with color, which is more aesthetic, because now I'm hell-bent on more scientific endeavors.

I stay up all night photographing. I'll listen to classical music; I'll make myself soup at about 2 a.m. And I'm usually alone. I often sign into the log of the Polaris Observatory Association — "alone but not lonely."

I'm with my stars; I am in close communion with the truly important things in my life. I am at one with the living and the dead. I'm in a magic world. I am aware of what is truly important and what is not. If I had my druthers, I'd like to spend the rest of my nights on my mountain. As it is, the log shows that I spent 45 or 50 nights on my mountain last year. This is a love affair. I am where I want to be.

— Phil Dombrowksi
Glastonbury, Connecticut

Mr. Dobrowski, an instructor of Earth sciences, has been a PROBLICOM blinker since the program's beginning in 1977.

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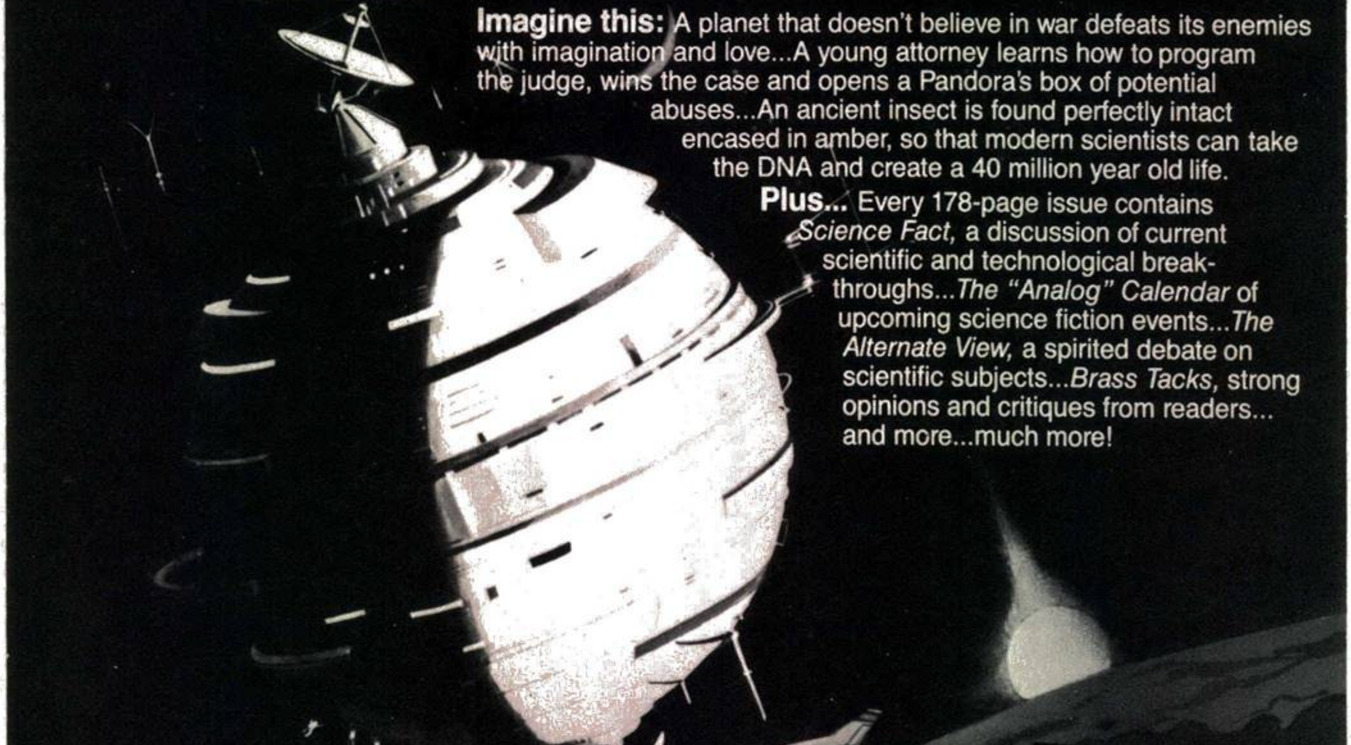

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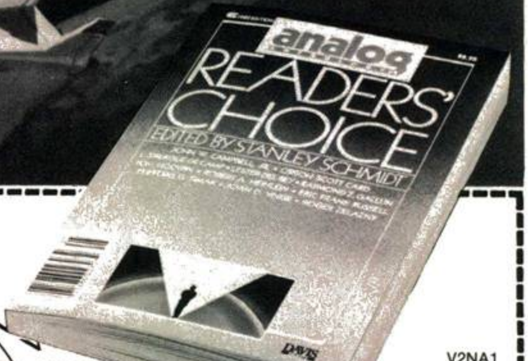

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eye on the sky

constellations steal the show

by Fred Schaaf

the wanderers

Saturn's stately departure from the evening sky signals the end of a lengthy period of planetary observing, and soon after Jupiter and Mars will accompany the ringed planet in the horizon glow.

Saturn does not reach conjunction with the Sun until mid-October, yet it will be difficult for North American observers to see it by late September. What will be the last night you can spot Saturn with your naked eye, or with binoculars? You should see it longer than Spica, even though both are about the same brightness. See what view you get of Saturn and Spica the evening of the 20th when Saturn has its final conjunction of the year with that star — passing 5° north of the Virgin's brightest luminary.

Saturn will not get fainter this decade as the rings are now opening up from our perspective, and will increase the planet's brightness.

Mercury reaches greatest elongation of 27° on the 6th, but the angle is southerly and unfavorable for North America. The gap between the Saturn-Spica pair and Mercury closes as Mercury hesitates among the stars, but then speeds back toward the Sun and is completely lost to view.

Jupiter reigns as the most conspicuous object in the southwest, traveling from Lambda Virginis on the way toward Alpha Librae this month. Observers around 40° N. will see Jupiter set 2½ hours after the Sun on September 1, and only 1½ hours after by September 30.

Mars is the most intriguing naked-eye planet this month. In the first weeks of September the gaps between Saturn and Jupiter, and Jupiter and Mars, are equally large, but both separations increase as Jupiter pulls away from Saturn and Mars outdistances both. Mars will be as bright as Saturn and Spica this month, but is positioned much better: 60° to 70° from the Sun.

In late September Mars passes through the dense Milky Way field surrounding the head of Scorpius. Just before passing 42′ north of Delta Scorpii (Dschubba) on the evening of the 22nd, Mars has a conjunction with **Uranus**. The 1st magnitude planet will pass just less than 1½° south of 6th magnitude Uranus during the evenings of September 21 and 22 — as the nearly half-lit **Moon** hangs suspended 5° north of Mars.

By the evening of the 26th, the Moon has moved several degrees, but an outstanding conjunction will occur. By that night the asteroid **Ceres**, at magnitude 8½, will pass just 5′ north of Uranus. Perhaps the most amazing fact is this is by no means the closest conjunction of planets or important minor planets for this year. That distinction falls to the 1½′ separation between Venus and Uranus in November. Unfortunately they will be very close to the Sun when this conjunction takes place.

The escapades of Mars are not over after its passage through the Scorpion's head. On the final days of September, watch it move closer and closer to a confrontation with its "rival" — Antares, the heart of the Scorpion. The actual conjunction between the two occurs on the night of October 2/3, but you'll want to start comparing their magnitudes and color before this date. Does Antares really rival Mars in color and brightness?

The elongation of **Venus** shrinks rapidly during September, but the angle of the ecliptic in the dawn sky at autumn equinox is so favorable that even at month's end, Venus rises more than 45 minutes ahead of the Sun even though less than 10° separates them! The -3.4 magnitude Morning Star has a conjunction on the morning of September 7, when it appears a mere 44′ north of 1st magnitude Regulus.

the starry sky

The constellation **Cygnus** the swan contains a wider and richer assortment of deep-sky objects than most others, and many of them are visible to the naked eye. The long form of Cygnus passes directly through the zenith for United States observers during September.

As autumn begins and most birds wing their way south, the grand swan of the heavens flies southwest, straight down the Milky Way band. Its brightest star is **Deneb**, which means "tail." A look at Cygnus reveals the long neck and head with the stars **Gamma Cygni** (Sadr) and **Beta Cygni** (Albireo).

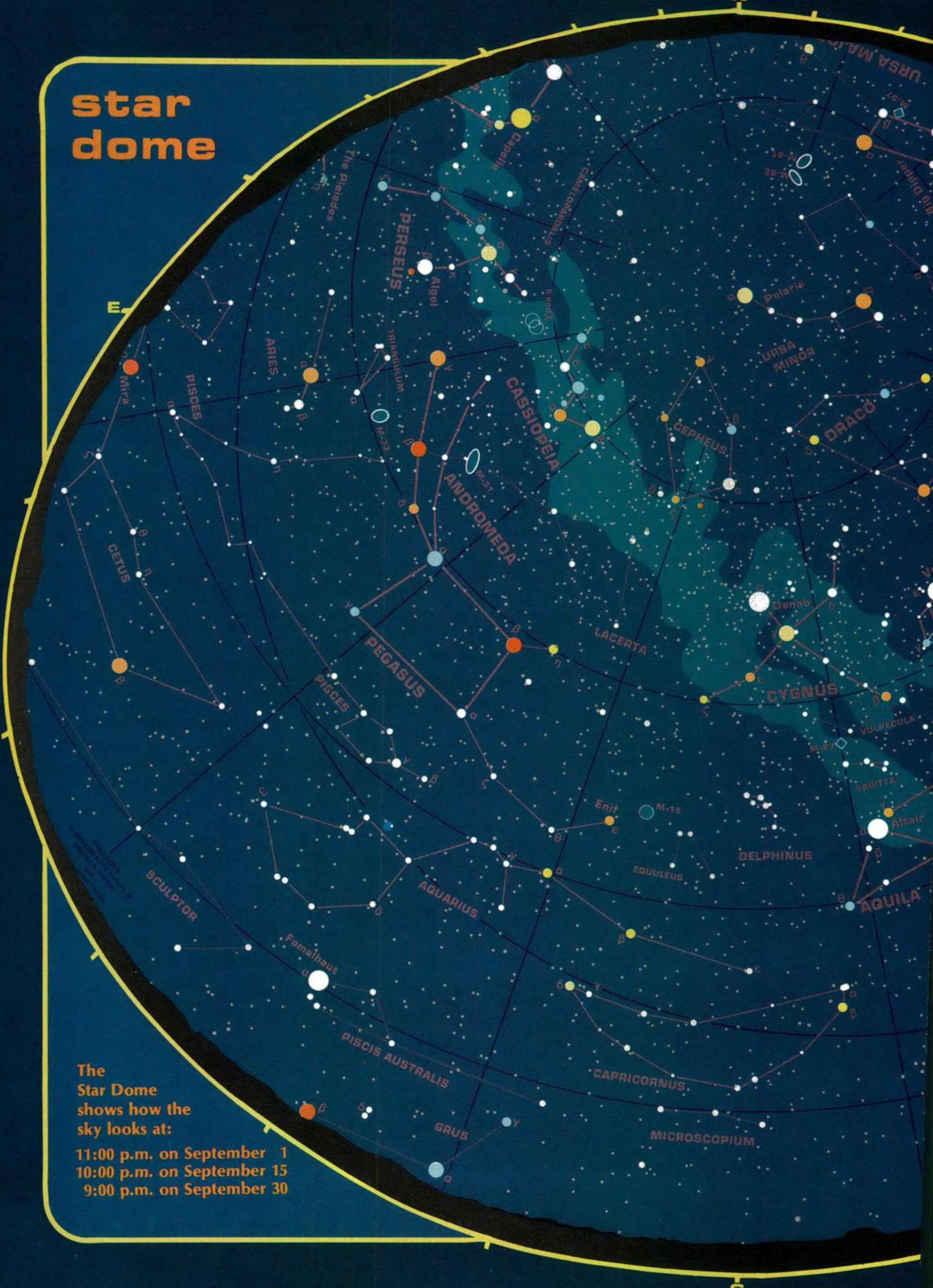
Albireo is a favorite object for observers on summer and early autumn nights because it is a lovely double star of gold and blue. Steadily held or mounted good quality binoculars will just separate the pair providing a spectacular view whether or not you have a telescope.

Even splendid Albireo has competition from other double stars in Cygnus. Try the **Omicron Cygni** system. Under good conditions the naked eye shows Omicron^1 and Omicron^2 as a close pair, 5½′ apart, not far from **32 Cygni** — the Omicron duo and 32 Cygni are conspicuous to the northwest of Deneb. If you have binoculars, you can even detect a third, fainter star in the Omicron system.

Yet another double in Cygnus is worth a naked-eye glimpse, even though you need a telescope to split it — **61 Cygni**, one of our closest

The sprawling summer Milky Way extends upward from Sagittarius to Scutum, but before long these constellations will set in *the evening twilight glow.* Jack Brisbin made this portrait of our galaxy with a 6½-minute guided exposure on Fuji 400 film through a 50mm lens at f/2.

star dome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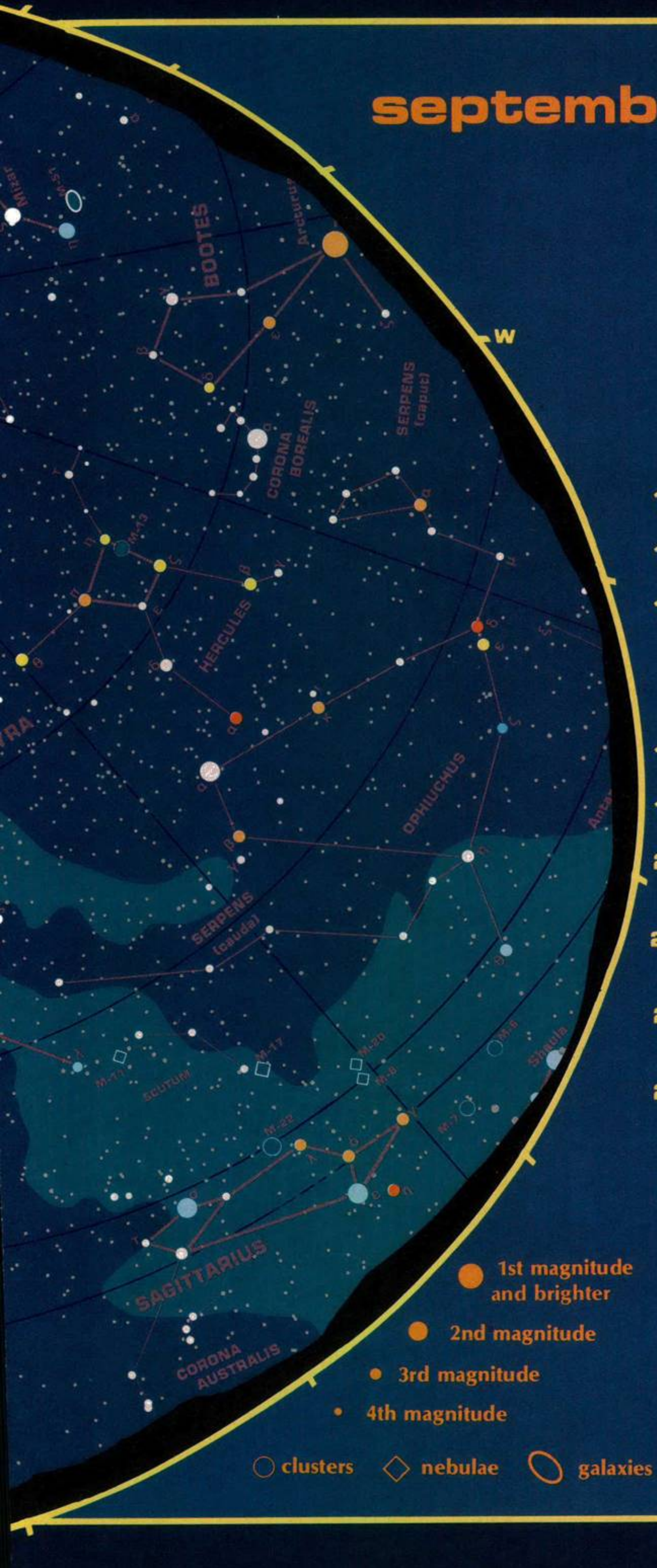
The Star Dome shows how the sky looks at:

11:00 p.m. on September 1
10:00 p.m. on September 15
9:00 p.m. on September 30

september sky almanac

3rd	Full Moon is at 8:28 a.m. EDT.
6th	Mercury is at greatest eastern elongation in the evening sky. Despite Mercury's large angular separation from the Sun (27°), the line between it and the Sun makes a shallow angle with the horizon, so the planet will be difficult to see.
9th	Venus is at perihelion.
10th	Last Quarter Moon is at 1:19 p.m. EDT.
13th	The Moon is at perigee this afternoon: 228,354 miles.
15th	By midnight (daylight time), Orion will be up and visible over the eastern horizon with the rest of winter's constellations to follow during the early morning hours.
17th	New Moon happens at 8:09 a.m. EDT.
19th	The crescent Moon lies to the east of Saturn tonight.
20th	A slightly fuller crescent Moon will lie to the east of Jupiter tonight.
22nd	The Moon will be 5° north of Mars, and Mars 1.5° south of Uranus tonight.
23rd	The equinox is at 4:46 a.m. EDT; Fall begins for the northern hemisphere.
25th	The Moon is at First Quarter at 12:07 a.m. EDT, and at apogee in the afternoon: 251,096 miles.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BOOTES
Arcturus
W
SERPENS (caput)
CORONA BOREALIS
M-13
HERCULES
LYRA
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SERPENS (cauda)
SCUTUM
M-11
M-17
M-20
M-8
M-6
M-7
Shaula
M-22
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CORONA AUSTRALIS
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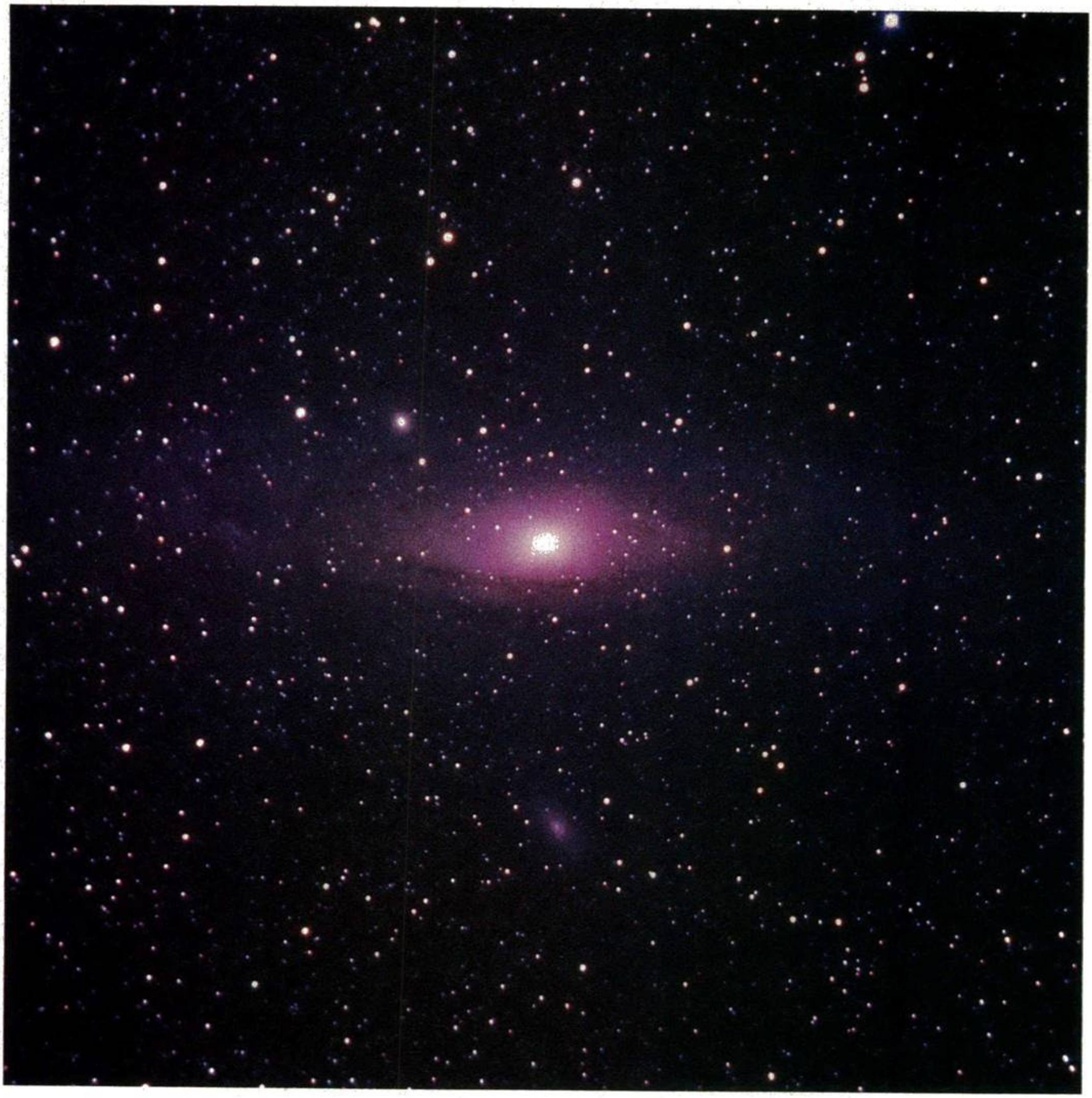


One showpiece in the rising group of fall constellations is the Great Andromeda Galaxy, M-31, the fuzzy spike above the bright star Mu. Binoculars or low-power scopes will help you trace the outline of this distant galaxy. John Kerns photographed this stellar pinwheel with a 45-minute exposure on hypered Fuji 400 through a 4½-inch f/5 reflector.

neighbors in space. Astronomers give fascinating evidence for a third companion of very small mass in this system. When you gaze at this dim point of light, muse on the fact that this flickering star is likely to have at least one planet.

Cygnus also holds **M-39**, an open star cluster visible to the naked eye in dark skies. With low magnification its triangular shape slightly resembles a lesser Pleiades. You'll find it about 9° northwest of Deneb.

If you want to just relax and peruse the richness of stars with naked eye or binoculars, Cygnus is a good place to start. With the naked eye you can study the **Cygnus Star Cloud** in the midst of the constellation and detect the bright patch of the **North America Nebula** following Deneb across the sky. Occasionally — if sky conditions are superbly dark — you'll even see the brightest part of the Veil Nebula.

Cygnus has been the scene of many fine novae, including the 1975 outburst which flared up to nearly rival Deneb. If you gaze often at the rich areas of the heavens like Cygnus, you greatly increase your chance of catching such a brief, rare, and spectacular event.

Although Cygnus is September's feature constellation, plenty of others capture our attention too. Both **Aquila** and **Lyra** are still well-placed with their bright gems **Altair** and **Vega**. And don't let summer slip away without looking at the lesser constellations near the **Summer Triangle** of Vega, Altair, and Deneb.

If you draw the imaginary lines of the Triangle, you will find that **Sagitta** fills the Altair corner of the huge pattern. You'll need dark skies to trace out Sagitta with the naked eye, but whatever your skies are like, Sagitta is your guide to finding two interesting binocular sights.

Look for the glow of the big **Dumbbell Nebula**, brightest of the planetary nebulae located a few degrees north of Sagitta's eastern end. You'll find the Dumbbell next to the star **14 Vulpecula**, in the dim constellation of the little fox.

Also within Vulpecula, and located northwest of the western end of Sagitta, is the little-known group of stars known variously as Collinder 399, Brocchi's Cluster, or **The Coathanger**. This peculiar-shaped grouping contains several 5th magnitude stars and is best with low magnification. The Coathanger lies on the line of the Summer Triangle that connects Altair and Vega.

One more attractive little constellation in this region is **Delphinus** the dolphin, which lies just east of the Summer Triangle and the Milky Way band. This compact shape of 3rd, 4th and 5th magnitude stars is unmistakable once you locate it.

If you let your eyes wander far south and somewhat east from Delphinus, you'll notice the contrast between the richly starred Summer Triangle area and this nearly vacant expanse. Low in the south sits the first of the huge, dim constellations — **Capricornus** the seagoat. Its west end is marked by the naked-eye double star **Giedi** (Alpha Capricorni) and the star **Dabih** (Beta Capricorni); its east end is **Deneb Algiedi**. In between is a scant outline of 4th magnitude stars that the 6th magnitude asteroid Vesta creeps through this month.

skylore

"Only the eagle, only he, can look at the Sun and not go blind," wrote a poet. An old legend says the eagle has each of its young gaze upon the Sun to separate the weak from the strong. This king of birds is one of the most popular and potent symbols from the animal world. Its stellar representative, Aquila, has shared in this heritage.

The constellation has been an eagle in many of the ancient occidental cultures, and it is possible that Aquila appears on an Euphratean stone star map from 1200 B.C. with the name Idzu Zamama — Eagle, the Living Eye.

Gertrude and James Jobes say that Zu was a storm eagle who was slain by Ninurta. Ninurta, also called Ningirsu, was one of the greatest Sumerian gods, and he has been identified with the constellation Orion. He too was a boisterous personage and a great warrior and hunter. He led one side in a war which involved all creation. Even stones took sides, and those who were with the victorious force of Ninurta became shining ones like lapis lazuli and amethyst, whereas the others were ever after "trodden under foot in disdain."

Another story about Zu the evil storm-eagle comes from the Babylonian legend in which he stole the Tablets of Fate, whose possession conferred omnipotence. Among all the gods, only Marduk was willing to attempt the recovery of the tablets. When Marduk got them and overcame the thief Zu, the tablets and the universe became rightfully his to rule, thus passing to him from the old god Anu of the Sumerians. The Jobeses also suggest a link between our starry eagle and other Assyro-Babylonian eagles: one called Alula, and one called Alallu who supposedly belonged to the famous hero Gilgamesh.

Since eagles and vultures were often confused with each other by the Greeks and Romans, Aquila was sometimes called Vultur Volans (Flying Vulture), which came into Old English as the Flying Grype. Otherwise, this constellation was always an eagle — usually Jove's according to the Romans.

The Eagle bore Jove's thunderbolts and is said to have carried up to Olympus the fair youth Ganymede, who is sometimes regarded as Aquarius, a constellation not too distant from Aquila. This eagle also may have brought nectar to Zeus when the god's mother hid Zeus from the devouring father Cronus.

According to R.H. Allen, the Latin poet Ovid wrote that a king called Merops was rewarded by being turned into the eagle of the starry sky. Allen says this Merops was king of Cos — an island not to be confused with Chios — but he claims that some Latin writers thought the man so rewarded was "some Aethiopian king like Cepheus."

The name Merops means "bee-eater" or "eloquent," as does the name Merope, whom many amateur astronomers know as one of the Pleiades. The Arabs called the star group of Alpha, Beta and Gamma Aquila, Al Nasr al Tair, the Flying Eagle, giving us the name of the pattern's brightest star. The Persian name Shahin tara zed, the Star-striking Falcon, gives us the names Alshain and Tarazed for Beta and Gamma Aquilae respectively. This line of three bright stars is known as Taushaugjil, Hunting Eagle, to the Turks. The Hebrew name was Neshr, an Eagle, Falcon or Vulture.

There is also an old Greek ornithological legend which tells of the swan overcoming the eagle's attack to defeat him: in the heavens, it does appear as though it is banking aside to avoid the oncoming Cygnus. Also in ancient times, two of the enemies of the eagle were reputed to be the dolphin and the snake, which are indeed found to either side of Aquila in the forms of Delphinus and Serpens. Aquila also had some of its stars long used to form the now-forgotten constellation of Antinous (a youth beloved by Emperor Hadrian).

Not all cultures have found an eagle in the stars of Aquila. A very ancient Chinese imaging has these stars as the draught oxen. And the Australian aborigines saw our Aquila as Totyarguil, a figure in one of their myths who was killed by an evil water-sprite — their eagle of the heavens was Sirius.

ASTRONOMY
IN FOCUS

Inner Voyages

Sir / As I study astronomy, I sometimes feel that the beauty of it all is clouded by those whining about the government and budget cuts. We, as astronomers, must assume responsibility for our own field of interest. We must let the dead images of the past fall away and begin now to build new ones. Any support we receive, we should accept with gratitude.

Let's face it, the government wants that which can help the government. Although the study of astronomy is sometimes useful in industry, it mostly appeals to those who are curious about their universe. It is pretty much established that we humans are on the only planet that will sustain us in our daily life. Therefore, space exploration does not even fall under the heading of government any more. That is why we as astronomers must take on this responsibility. If we can go on with life and build our own support, things will work out much better. We are in the position of the whining child who is ignored by the parent. As soon as the child finds something to occupy himself, the parent becomes interested. If *we* can't find astronomy more absorbing than whining, how can we expect others to show an interest in the most beautiful science?

What the government has done to halt space exploration is of no concern now. We must realize that we are always living in the present, and that we can grow inwardly by our experiences with astronomy now. When was the last time *you* went to the library and looked at the 3-D pictures of the Moon and Mars? When was the last time you took a walk in the starlight and contemplated the beauty and wonder of the universe? There are many experiences happening right now that we could be having if we shift our attention to them.

We should be very grateful for the support we have gotten thus far from the government. Galileo was fascinated by the "ears" of Saturn. Cassini was stunned to discover that there was a division in the rings. The United States sent a camera to Saturn and obtained high resolution shots which revealed thousands of rings and swirling surface features. This knowledge has been a secret of nature until our generation, yet we are not happy with it. Our government has been good enough to fund similar projects to other planets and, of course, the Moon. We should receive any support with gratitude.

Well, fellow astronomers, what do you say we let the clouds of blame dissipate so that we can see the cosmos clearly? We can let the government handle matters here on Earth while we each take our own personal voyage through the cosmos. Galileo, Newton, and Einstein all worked with moderate equipment, yet they were able to make great discoveries. Although we are fortunate today to have such elaborate equipment available, we must never lose sight of the wonder of it all, for that is where the true discovery is made. Go within.

Bill Peck
Valdosta, GA

— Should Galileo, Newton, and Einstein also have gone within? Where would we be if they had?

Exploit Space, Not Earth

Sir / The Earth has only a limited amount of resources, and, while gas and oil may last for 50 to 100 years, what do we do after that? Not only are we low on energy sources, we are also low on many metals — just ask the Department of Defense how much we depend on other countries for rare metals.

Space offers virtually unlimited resources, clean energy, and room to expand. The time may not be far off when we have to decide between mining the land or farming it. What would the "Back to the Land-ers" have us do? Should we get into a war over the last resources? That is what is going to happen unless we get on the ball and start developing those in space.

The Moon's a pretty place, but if it comes to a choice between fighting on Earth over some metal deposit or strip mining Mare Tranquilitatis — well, the choice is clear to me.

Toliver Singer
Rosebud, SD

Petition for Space

Sir / I read your May issue with a great churning of emotions.

I took a hopeful ride to the Planets or Bust, marveled at the Topography of the Terrestrial Planets, was fascinated by the interview with Dr. Fred Scarf, and amusingly shaken by some amateur tough talk. My wonder and amazement with our universe was stirred, and my yearning to explore the heavens first-hand strengthened.

Then I met with the harsh facts of our short-sighted government, and felt the pain from the end of our role in deep space. Yet, in the face of these continuing budgetary cuts, we cannot give up. We must strive harder in pursuit of a strong, active space program.

I would like to inform your readers of a nation-wide petition drive currently underway, sponsored by the Piedmont Advocacy for Space, in conjunction with Spaceweek '82. This is a chance for the American people to place a collective voice into their government, opposing these detrimental cuts.

Information and copies of the petition can be obtained by writing:

S.J. Reidhead
c/o P.A.S
P.O. Box 197
Fair Play, SC 29643

It is up to us, the people of the United States, to prepare our way into the future. Our voice does make a difference.

Charles P. Smith
Long Lake, MN

Space vs. Welfare *ca.*1939

Sir / If you don't mind another comment on the "Space vs. Welfare" subject, here is one by David O. Woodbury in the *Glass Giant of Palomar* (1939). I think he said it all, way back then:

"Let those who complain that too much money is being spent on abstract knowledge while people are starving remember this: the alternative to knowledge is savagery. Their very existence as stowaways on the voyage of civilization is owing to advances in science which permit some to live without doing their share of the work. Let them be tolerant, then, lest by encumbering the useful ones they destroy the thing which keeps them alive!"

I also commend you on your best issue yet; the April ASTRONOMY was chock full of interesting and informative articles, and it was just as good on the second reading. Now I am going over it for the third time.

Fred L. Redburn
Lubbock, TX

Centaurian Oort Cloud Unlikely

Sir / Patrick Stinson's suggestion (April, In Focus) that the Sun's Oort Cloud of comets may interact with a similar comet cloud around the centaurian system is interesting, but highly unlikely.

Recent dynamical studies indicate that the Oort Cloud probably has a radius of about 1 light-year, and very few comets have aphelia beyond 2 light-years. For the centaurian system, the greater mass leads to an effective cloud radius of about 1.4 light-years. However, Proxima (Alpha Centauri C) orbits on the inner fringes of that cloud and its perturbations would likely deplete the total population severely.

In addition, any comet approaching the solar system from Alpha Centauri would have the velocity of that system relative to the Sun — about 32 km/sec. Velocities that high would tend to minimize the focusing effect of the Sun's gravity. (Also remember that we can't see a comet until it gets to within about 5 AU of the Sun.)

If a comet came into the solar system with an excess velocity of 32 km/sec, it would have an easily-recognizable high orbital eccentricity. The highest on record is 1.000643 — which corresponds to a excess hyperbolic velocity of only 0.8 km/sec — and is probably due more to the uncertainties of the orbit determination than to an interstellar origin.

Paul Weissman
Jet Propulsion Laboratory
Pasadena, CA

Campaign for Space

Sir / Thank you for including the Campaign for Space among the space activist groups in May's "Astro-Sources."

The Campaign for Space is unique among space groups in that we are a political action committee. During this election year, we are making financial contributions to deserving pro-space candidates. By helping elect pro-space congressmen, we can assure that NASA will receive adequate and stable funding. After all, NASA's budget is determined by the 536 elected representatives.
Our new address is:

Campaign for Space
P.O. Box 1526
Bainbridge, GA 31717

Thomas J. Frieling
Executive Director
Campaign for Space
Bainbridge, GA

Ooops!

The *Wall Street Journal* ad mentioned in the AstroNews article on Spacewatch in the June ASTRONOMY was a classified ad paid for by a donor, not a full-page ad. No Spacewatch or NASA funds were spent on it.

Revealing the Universe, reviewed in the July issue, was authored by James Cornell and Alan P. Lightman.

behind the scenes | discovering a new world

First, if you purchased this copy of ASTRONOMY at a newsstand, I'd like to welcome you as a new reader. You might not have seen us before, although we've been publishing since 1973, because this September issue marks the first time we've been broadly distributed to a large number of newsstands. On behalf of the staff of ASTRONOMY and those readers who receive ASTRONOMY in the mail every month, we hope you enjoy the world of astronomy.

Second, I'd like to direct every reader to our feature article on Venus. When I was young, Venus stood out from all the other planets I read about or watched through my telescope. Venus seemed uniquely — how can I say it nicely? — "boring." Venus is completely cloud-covered, so there's almost nothing to see with a telescope except its phases, and books on astronomy had virtually nothing to say about it. Mars, Jupiter, magnificent Saturn always offered a good show and plenty of tempting mysteries to make interesting reading. I even did part of my Master's degree research on Io, one of the satellites of Jupiter, which was known to be unusual even before Voyager flew past and showed what an utterly bizarre world it is.

But Venus has made a comeback, at least to my mind. Over the last three or four years, Earth-based radar, NASA's Pioneer Venus orbiter and the Soviet and American landers have provided a trickle of data revealing, one tiny glimpse at a time, a truly fascinating planet. Venus raises questions about the priorities we should hold in humanity's use of space: Should we devote our nation's limited energies to learning about Earth's "sister" world, or go to comets and the outer planets?

Venus also poses profound questions about use of our own world. Perhaps what may have once been our sister planet can give humanity an incredibly important benefit — the understanding of our own planet.

Sincerely,

Richard Berry

Richard Berry
Editor

gazer's
gazette

learning the fall constellations

We can thank the ancient Romans, Arabs, and Greeks for the groupings of stars we recognize as constellations. Those early civilizations organized the myriad points into figures and groups of importance, mentally arranging all the stars into a fabric interwoven with mythological people and animals.

To a city dweller, the first glance in a dark country sky can be an overwhelming experience. The constellations and bright stars that make them up were obvious at home in the suburban glow, but away from city lights, those familiar patterns dissolve into a star-sprinkled tapestry of more than 2,000 individual luminaries. The autumn sky contains many bright, easily identified constellations, as well as fainter, more obscure groups. All you need is a dark, moonless night and a little bit of imagination to help you hunt these patterns. Let's start our celestial tour in the west, since those constellations set first.

Lying just above the horizon an hour after sunset is the sprawling constellation Scorpius the scorpion, one of the few star patterns that looks like its namesake. You can zero in on the heart of Scorpius by identifying its brightest star Antares, noticeably red and about 10° above the horizon. It will be the brightest star in the area and you won't miss it unless the sky's hazy. Once you've spotted Antares, trace the curving outline of Scorpius to the south and east until you come to two bright stars marking the stinger of the scorpion low on the horizon. Unfortunately, Scorpius never rises very far above the southwestern horizon for northern viewers.

Just east of Scorpius lies another constellation of the zodiac, Sagittarius the archer. Sagittarius also stays low, but is easy to spot because its bright stars form a pattern resembling a teapot. When you look in this direction you peer into the heart of our Galaxy. You can see the nebulous Milky Way if you're out in the country, but haze or clouds will obscure this subtle detail. For telescopic or binocular observers, Sagittarius abounds with beautiful sights.

Many star clusters, nebulae and other deep-sky objects lie in this region below the threshold of sight, but some of these objects are bright enough to see with your naked eye even though they're thousands of light-years away. Chances are if you think you see hazy patches in this area, you probably do — they're really distant clusters of stars or gaseous clouds where astronomers believe stars are born. Spend a few moments scanning this area with binoculars and you'll be rewarded.

Moving north you'll come to a huge isosceles triangle formed by three bright stars. It is the Summer Triangle, not a constellation but a familiar grouping nonetheless. The Summer Triangle is formed by stars in three constellations — Vega, brightest star in the constellation Lyra the harp; Deneb, in Cygnus the swan, also called the Northern Cross; and Altair, the brightest star in Aquila the eagle. Of these three, Vega is brightest. In fact, it is the brightest star in the sky at this time of year, a brilliant blue-white diamond set against black velvet.

Lyra floats directly overhead during autumn, and although it is small, the harp's shape is easy to pick out. Vega forms a small triangle with two fainter stars connected to a small parallelogram of equally faint stars. It's a good thing Vega acts as a beacon, otherwise Lyra wouldn't be a very noticeable group!

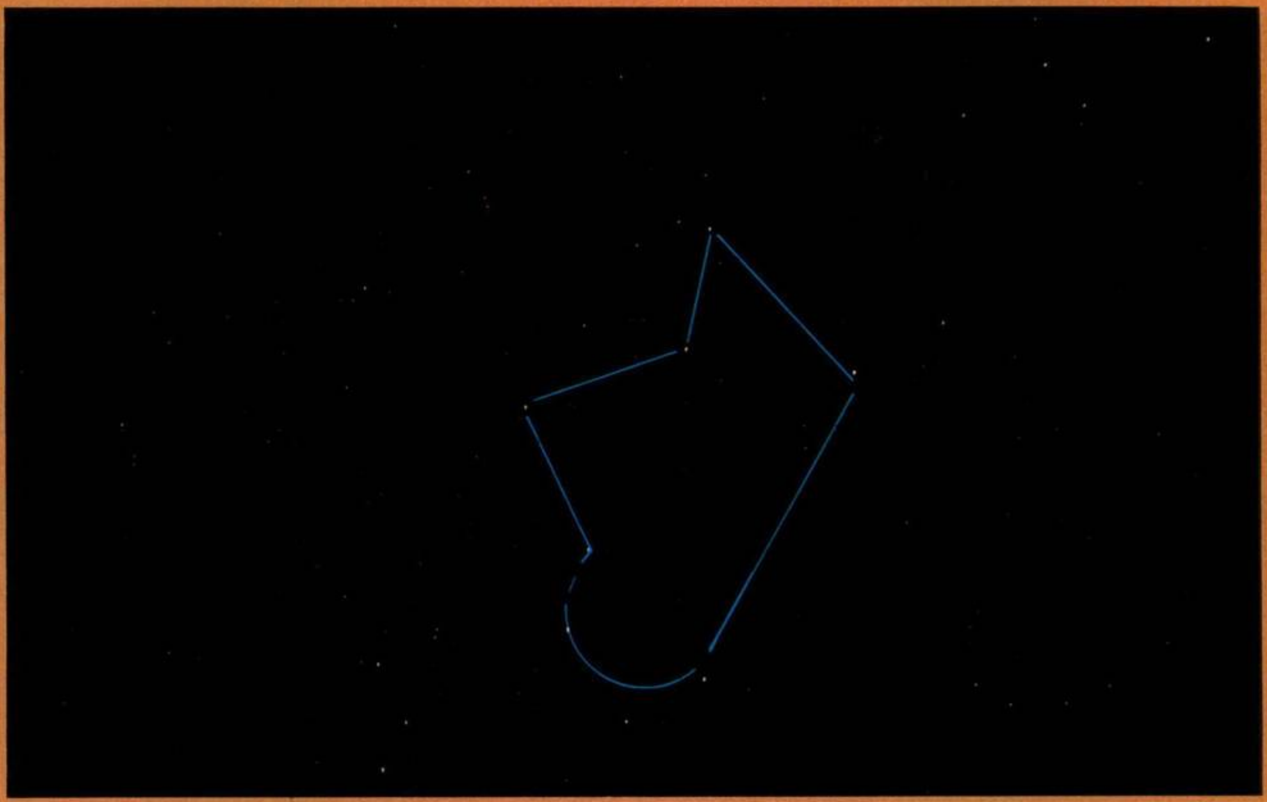
Cygnus the swan, or the Northern Cross, lies to the east of Lyra, and Deneb sits at the top shining with a bright, white light. Draw an imaginary line straight down through the crucifix and you'll find Albireo, one of the most famous double stars in the heavens. A telescope resolves this "single" star into two glittering points of contrasting color — yellow and blue. If you have a telescope, no matter how small, be sure to inspect the true nature of this lovely pair.

South of these two constellations flies Aquila, the eagle, whose only recognizable part is a line of three stars with Altair in the middle. Altair falls between Vega and Deneb in brightness, and is pale yellow in color.

Look down in the northeast from Cygnus and you'll spot a group of stars resembling a "W" or an "M." This constellation is Cassiopeia the queen. Legends indicate Cassiopeia was vain, and as a punishment, Zeus placed her in the sky only able to sit upright in her throne for six months. The rest of the year she must clutch the sides of her chair so she doesn't fall out — thus the M and W shapes. The brightest star, Caph, symbolizes the back of her throne and is located at the tip of the right side of the W. The other bright star is Schedir, the breast, at the bottom of the W's right side. A portion of the Milky Way floats through this region making it a good area for binocular study.

Use Caph and Schedir as pointers to locate the faint constellation between Cygnus and Cassiopeia, Cepheus the king, that looks like an old-fashioned house with a pointed roof. Cepheus' main stars are faint, and he offers little to the naked eye observer, even though he did play an important role in the classical mythology of the constellations. Cepheus contains one star very important to astronomers, too — Delta Cephei, a star whose light output fluctuates regularly. Stars like Delta Cephei are called "the measuring sticks of the universe," because their changes in light allow astronomers to calculate the distance to other galaxies. Delta Cephei is the bright star closest to Cassiopeia.

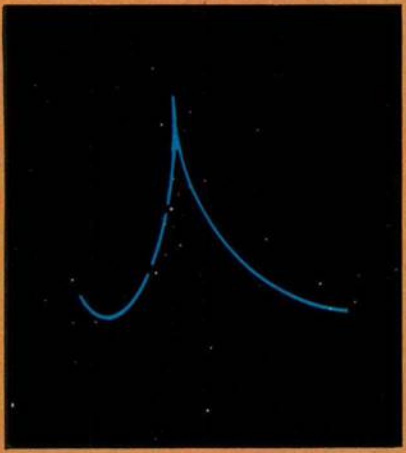
You'll find the constellations Pegasus the winged horse, and



Lying in the densest region of the Milky Way is Sagittarius the archer whose familiar pattern looks like a teapot.

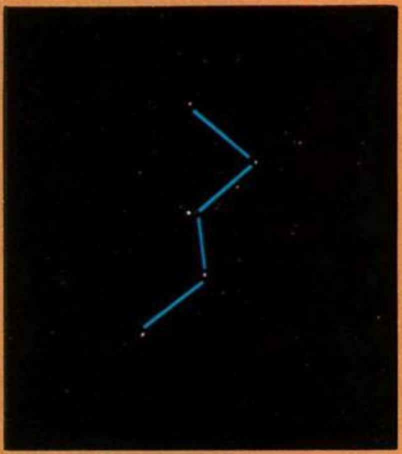
Photos by Stephen A. Walther unless otherwise noted

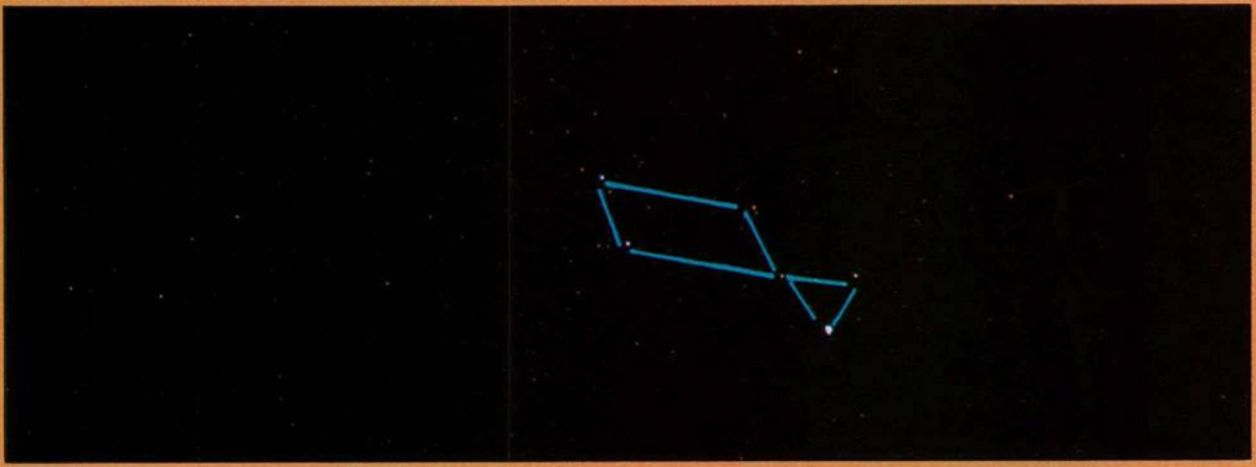
Low in the west at sunset creeps Scorpius the scorpion, a trailing curved line of stars with bright red Antares at its heart.



Curving gracefully in the northeast is Perseus the hero, complete with the famous Double Cluster — a beautiful sight even through opera glasses.

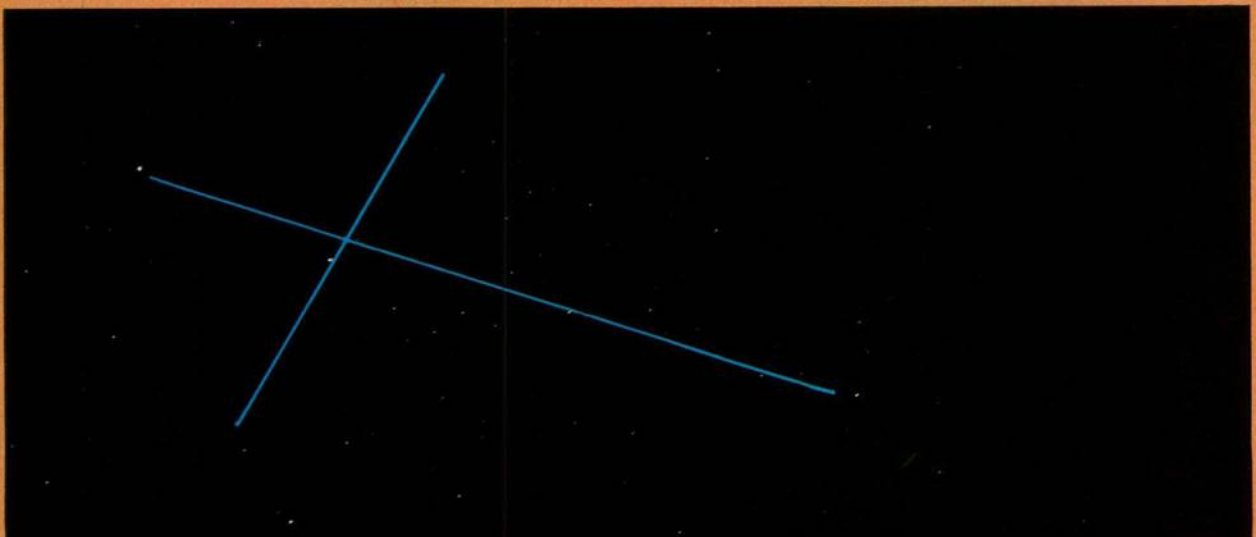
Cassiopeia the queen looks like an "M" or a "W" depending on the season. You can spot her rising in the northeast next to Perseus.

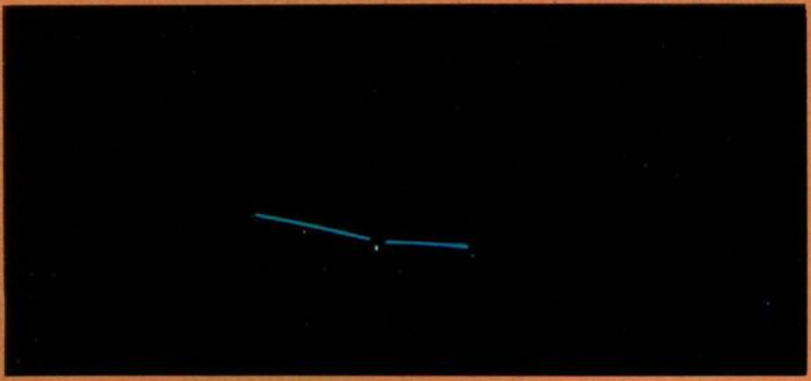




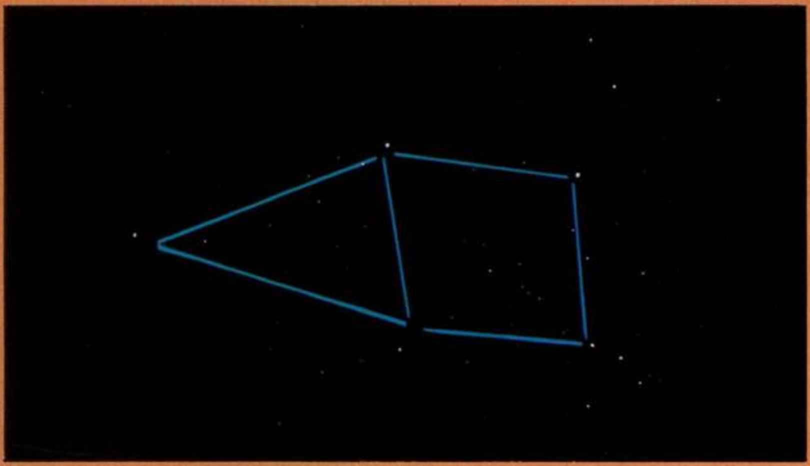
Next to Cygnus, and obvious because of Vega, the brightest star in the early evening sky, is the tiny constellation Lyra the harp.

Cygnus the swan flies high overhead at sunset and is shaped like a huge cross gliding straight down the summer Milky Way. Deep-sky objects abound in Cygnus.





Aquila the eagle is barren of stars except for bright yellow Altair that forms one corner of the Summer Triangle.



Cepheus the king is a faint circumpolar group that looks like a house with a pointed roof.

The Great Square of Pegasus peeks over the horizon about 9 p.m.; the star chains of Andromeda follow soon after.

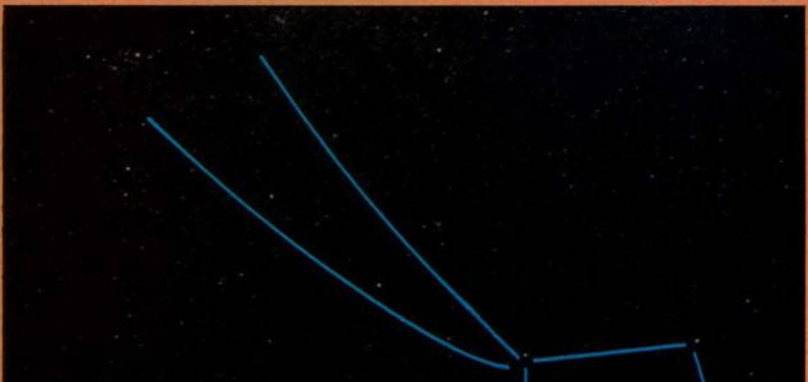


Photo by B. Wallis/R. Proven

Andromeda the maiden rising in the northeast about 10 p.m. The easiest part of Pegasus to recognize is the Great Square, one of the more obvious heavenly configurations; like the Summer Triangle it, too, is a useful pointer. Four stars of equal brightness form the Great Square. Clockwise from the upper right are Scheat, Markab, Algenib and Alpheratz. Pegasus is one of those constellations that doesn't look like its namesake, but the translation of the star names gives away its true identity. Scheat means "the horse's shoulder," Markab means something that is ridden or sat on, and Algenib is derived from the words meaning "side" or "wing." The remainder of Pegasus extends to the right (west) with his hind legs going up toward Cygnus. The upper left corner star in the Great Square is Alpheratz, shared with Andromeda.

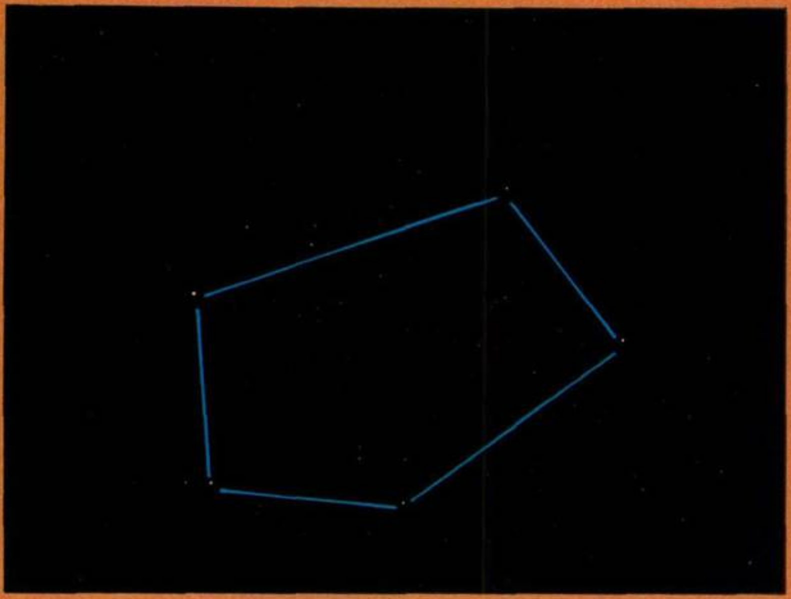
Andromeda the lovely maiden was rescued by Perseus after her father, Cepheus, chained her to a rock as a feast for a sea monster. She extends eastward in two languid arcs of stars representing her two legs. Start at Alpheratz, work your way back, and the two arcs will become obvious. Midway on the top arc you will notice a faint, oval smudge of light.

It is the Great Andromeda Galaxy, a colossal system of stars very similar to our own Milky Way but more than two million light-years away! It is the most distant object you can see with your naked eye. Take a look at it with binoculars and you'll be treated to a glorious sight. Astronomers study this massive stellar pinwheel to learn about processes in our own Galaxy. Remember that when you look at this galaxy you see it as it appeared over two million years ago; the light from it took that long to reach Earth.

If you continue on the line you drew through Pegasus into Andromeda, you'll intersect the constellation Perseus the hero. Not only did he save Andromeda from the clutches of a sea monster, but he killed that beast with the head of Medusa, whom he had just slain.

Perseus lies in a rich region of the sky that holds many rewards for the binocular observer. Just between Perseus and Cassiopeia you'll notice two faint patches of stars — the famous Double Cluster of Perseus, with more than 100 stars in each group. The Double Cluster is famed in mythology and poetry as one of the loveliest sights in the heavens, especially through binoculars. Perseus' shape is similar to Andromeda's: two gracefully curving chains of stars.

To the east, rising out of the horizon glow, is Auriga, the charioteer, with an easily recognizable shape and one bright yellow star called Capella. The



Auriga the charioteer, with its bright yellow star Capella, resembles a large pentagon. With binoculars, you can spot three faint star clusters here.

Taurus is easy to spot with the V-shaped Hyades and tightly knotted Pleiades. Orion stands out boldly in the southeast at midnight. Look at the fuzzy middle "star" in his dagger with binoculars.

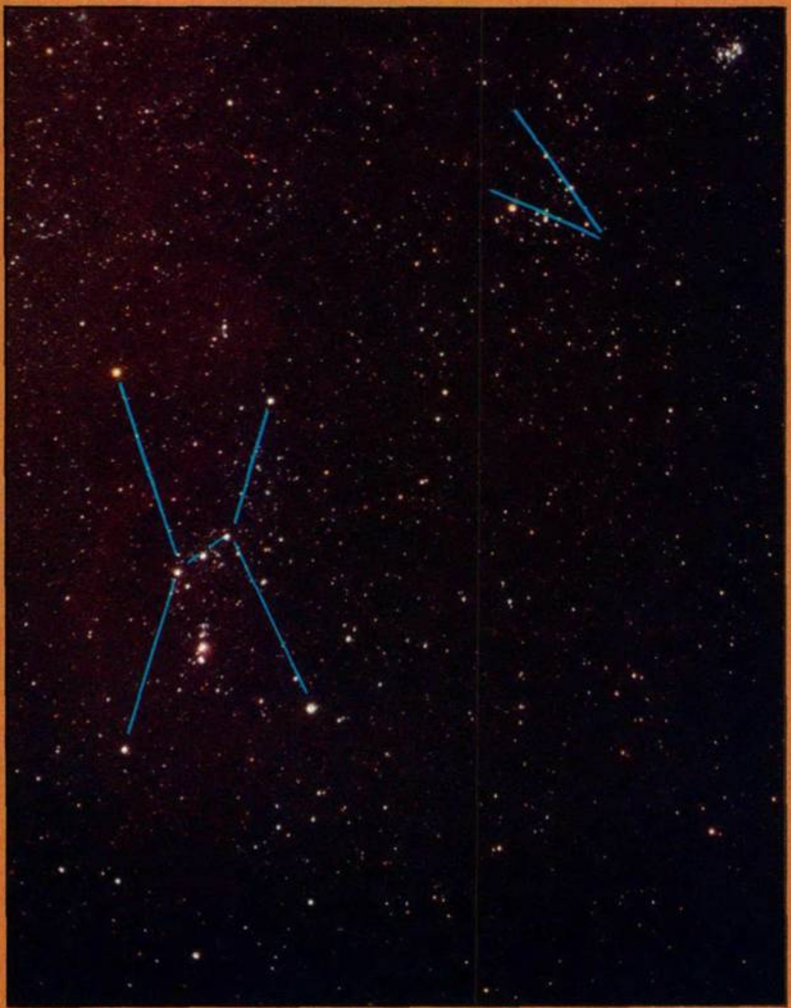


Photo by John Sanford

five bright stars including Capella form a huge pentagon in the sky, and in its bounds are several notable star clusters. This entire region bears close scrutiny with binoculars and telescopes, and also heralds the rising of winter constellations like Taurus and Orion.

Although these last two constellations don't reach the meridian until winter, they do rise between 11 p.m. and 12 a.m., and are certainly visible during the fall if you stay up late enough. By the time they peak above the horizon, you can bet that winter is not too far away.

Taurus the bull is a beautiful constellation easily recognized by its prominent V-shaped cluster of stars called the Hyades, and the bright red star Aldebaran that marks the end of that cluster. Above and to the west is another small cluster that symbolizes the heart of the bull. It is the loveliest of all clusters in the sky, the Pleiades, famed in more poetry than any other astronomical object. On a good night a sharp-eyed observer can detect only six stars, but the Pleiades were seven sisters in Greek mythology. Where is the lost sister?

From the V-shaped Hyades trace the outline of Taurus back to two stars that fix the endpoints of his horns. The star at the end of the upper horn is shared with Auriga.

Orion, the famed hunter, chases Taurus up into the sky with his club and shield outstretched. You can easily recognize Orion because he contains so many bright stars. Marking his left shoulder is the red giant star Betelgeuse; Rigel, the blue-white diamond at the bottom of the constellation marks his right kneecap. The most prominent feature of Orion is the equally spaced line of three stars in the center of the constellation that symbolize the hunter's belt.

Below his belt you can see some fainter stars and a fuzzy object. It is his "dagger," and the Great Orion Nebula, a glowing cloud of hydrogen gas. The nebula is just visible to the naked eye as a fuzzy spot, but binoculars or telescopes reveal the wispy, filamentary nature of this awesome object. When photographed, the nebula appears red because of the hydrogen, but to the naked eye it looks pale green.

Now you've been on a tour through the entire autumn sky, and have gazed up at those ancient assemblages of stars with a new understanding. They're not just a bunch of bright pinpoints, randomly scattered, but people and animals you can get to know with just a little effort and a few hours spent pondering the beauty of the heavens from your own backyard.

— *Berry Brunk*

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Meade® Deep-Space Telescope Systems

16″ Equatorial Reflector: **$1185.00**, complete! The Giant-Aperture, Deep-Space Telescope You Never Thought You Could Afford… Until Now

Ever expect to see the Great Nebula in Orion (M42) as a glowing blue-green ember? Or resolve the Hercules globular cluster (M13) to the core? Or observe the dust lanes and spiral structure in the Whirlpool Galaxy (M51)? Not just photographically, but **visually**. Now you can, and can afford to, observe these and countless hundreds of other objects as you've never seen them before. The incredible Meade DS-16, with **50%** more light-gathering area than other 13″ telescopes, has just opened up a new universe for you.

Consider the possibilities in astrophotography: Capture the glowing yellow-red detail of the Ring Nebula (M57), including the 15th-magnitude central star, in **4 minutes;** or the complete red, blue and green structure of the Orion Nebula, including the diffuse outer loop in **6 minutes;** the fiery-red gaseous detail of the Omega Nebula (M17) in **5 minutes;** the dust lanes and spiral detail of the Andromeda Galaxy (M31) in **5 minutes or less!** Exposure times so short you really don't need a drive corrector or guide telescope— so short that even a beginner can obtain astrophotos of exquisite detail.

Manufactured exclusively for Crown Optics by Meade Instruments Corp., the World's largest manufacturer of reflecting telescopes for the serious amateur, the DS-10 and DS-16 make available to the average amateur visual and photographic capabilities only dreamed of until now. Unlike competing large-aperture telescopes, the Meade DS-Series Telescopes include **Equatorial Mounts** as standard equipment: you track effortlessly along **one** axis, not along 2 simultaneous axes as with an alt-azimuth mounting. Add the optional Electric Motor Drive System and you're ready for fully automatic tracking and the deep-space photography you never thought possible.

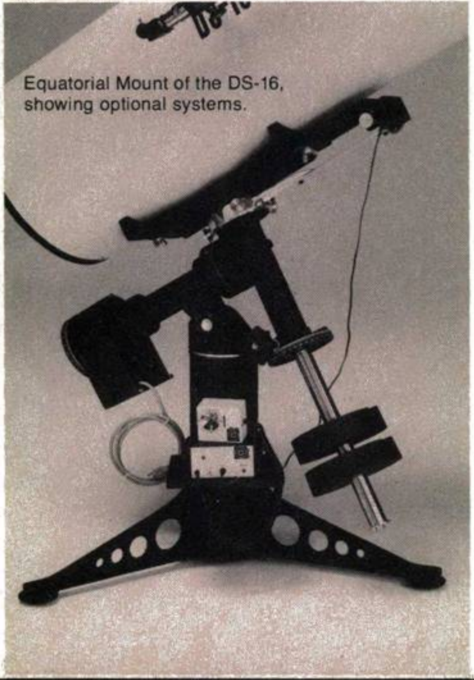
SPECIFICATIONS— Meade DS-10: 10″ f/4.5 Reflecting Telescope. With null-figured, diffraction-limited Pyrex parabolic primary mirror and matching (2.60″ M.A.) 1/10-wave flat elliptical secondary; #67 rack-and-pinion focuser at convenient observing position; Kellner 25mm (46×) eyepiece; Sonotube 12″ I.D. × 46″ long, sealed and attractively Zolatone coated; all-metal, precision-machined Equatorial Mount, with ultrasmooth nylon bearings and 1″ solid steel shafts; rock-solid, low-profile pier and tripod legs; locks on both axes. Complete: **$449.50**.

SPECIFICATIONS— Meade DS-16: 16″ f/4.5 Reflecting Telescope. With null-figured, diffraction-limited, Pyrex parabolic primary mirror and matching (4.00″ M.A.) 1/10-wave flat elliptical secondary; flotation mirror cell; #67 rack-and-pinion focuser at convenient observing position; Kellner 25mm (73×) eyepiece; Sonotube 18″ I.D. × 68″ long, sealed and attractively Zolatone coated; all-metal, precision-machined Equatorial Mount, with ultrasmooth Nylon bearings, 1½″ solid steel shafts, and 5″-dia. polar thrust surface; rock-solid, low-profile pier and tripod legs; locks on both axes. Complete **$1185.00**.

10″ Model DS-10

16″ Model DS-16

Shown equipped with optional motor drives, setting circles, viewfinders.



Equatorial Mount of the DS-16, showing optional systems.

OPTIONAL SYSTEMS

#787	**Electric Motor Drive System (115v./60Hz) for DS-10**	**$ 60.00 ppd.**
#897	**Electric Motor Worm-Gear Drive System (115v./60Hz) for DS-16**	**155.00 ppd.**

See our ad on the next page for the wide array of other optional accessories for the DS-10 and DS-16. These include: higher- and lower-power eyepieces; viewfinders; telenegative amplifiers; nebular filters; drive correctors and photoguide telescopes for long-exposure photography; camera adapters. The giant Meade #680 Focuser may also be ordered in place of the *standard* focuser on the DS-10 and DS-16. See Bulletin DS for details.

- Both models are **complete** instruments at the prices listed— no additional parts or accessories required to start observing.
- Easy Portability— Field set-up time is about 2 minutes for the DS-10, 5 minutes for the DS-16.
- The DS-10 and DS-16 carry the Meade Full-Year Limited Warranty.
- **Prompt shipment** on both models— Order by mail, or by dialing the Crown TOLL-FREE 800-number. (See next page for details.)
- All prices include packing; F.O.B. Costa Mesa, Calif.
- Delivery direct to your door by U.P.S. or truck freight.
- Send for **Free Bulletin DS,** with full details on these incredible deep-space telescopes, or enclose $3.00 for complete General Catalog of Meade astronomical products. (See next page for details.)

CROWNOPTICS, INC.
P.O. Box 8672, Newport Beach, Calif. 92660

Authorized Meade Dealer

For ordering information on the finest telescope accessories and parts, or on complete Schmidt-Cassegrains— all at Crown's super-discount prices— please turn the page . . .

The Widest Range of Premium-Grade Meade® Telescope Accessories, Parts, and Complete Schmidt-Cassegrains—from Crown Optics, America's Number One Superdiscount Source

Order TOLL-FREE on our nationwide 800-number!

PHOTO-GUIDE TELESCOPES— Each with coated, air-spaced objective, rack-and-pinion focuser, diagonal prism, 9mm crosshair eyepiece.

1— **Model 300PG:**	D=80mm (3.1″);	F=1200mm (f/15)		**$185.00 ppd.**
2— **Model 280PG:**	D=60mm (2.4″);	F=700mm (f/11.7)		**79.50 ppd.**
3— **Model 210PG:**	D=50mm (2.0″);	F=600mm (f/12)		**57.50 ppd.**
Mounting Rings:	for #210PG		per. pr.	**9.75 ppd.**
	for #280PG, #300PG		per. pr.	**12.50 ppd.**

RACK-AND-PINION FOCUSERS— All 3 models include helical-cut rack and variable-tension adjustment for ultra-smooth focusing without backlash. Universal bases fit all tube sizes. Standard 1¼″ eyepiece holders.

4— **Model 67** — Strong, lightweight design for 4″ to 10″ telescopes. 2-3/16″ travel. An excellent value. **$23.50 ppd.**

5— **Model 640** — A heavy-duty deluxe focuser for 6″ to 16″ telescopes. Full 3″ travel for both visual and photographic applications. **$36.95 ppd.**

6— **Model 680** — Accepts both 1¼″ and 2″ eyepieces. Full 3″ travel for photo or visual observing with 6″ to 16″ telescopes. **$44.95 ppd.**

ACCESSORY CASES— For secure storage of eyepieces, Barlows, filters.

7— **Model 54:** Thick-wall polyethylene with latch and handle. Holds 7 eyepieces & Barlow, filters. Dims. 12″ × 8″ × 3¾″ **$12.50 ppd.**

8— **Model 50:** Luggage-quality metal case with 2 latches, handle; foam custom fits to your accessories.
Dims. 20″ × 12″ × 6½″ .... **$39.50 ppd.**

NEBULAR FILTERS— Revolutionary 3-channel filters block natural airglow & sodium and mercury emissions from city lights. Dramatically improve telescope performance visually and photographically.

9— **Model 907:**	18mm aperture, for .965″ O.D. eyepieces	**$42.50 ppd.**
10— **Model 908:**	23mm aperture, for 1¼″ O.D. eyepieces	**$49.95 ppd.**
11— **Model 911:**	36mm aperture, threads directly onto rear-cell of Meade and Celestron Schmidt-Cassegrains.	**$69.50 ppd.**

12— **PHOTO-VISUAL COLOR FILTERS**— Top quality optical glass, dyed-in-the-mass, with excellent spectral homogeneity. Thread directly into 1¼″ O.D. barrels. Filters may be piggybacked. **#8 Light Yellow—#11 Yellow-Green—#12 Yellow—#21 Orange—#23A Light Red—#25A Red—#47 Violet—#58 Green—#80A Blue—Polarizer (30% transmission).** Each filter: **$7.50 ppd.** Set of any 6: **$43.50 ppd.**—Full set of 10: **$70.00 ppd.**

13— **VARIPAK DRIVE CORRECTOR**— **Model 43:** Supercompact 2″ × 3″ × 4″ design. Fast-slow pushbuttons. Variable speed control. Operates from 12 volts D.C., plugs into standard auto cigarette lighter. The 12-watt output is sufficient for most telescopes to 14″ aperture .... **$59.50 ppd.**

14— **VARIGUIDE DRIVE CORRECTOR**— **Model 41:** The finest R.A. drive corrector available. Includes aircraft-type joystick controller for continuously variable correction rates. Variable speed control. Use with any telescope drive rated up to 12 watts. Operates from 12 v. D.C. or 115 v. A.C. **$110.00 ppd.**

15— **6 × 30mm VIEWFINDER**— **Model 631:** Same unit supplied as standard equipment on Meade 6″ and 8″ reflecting telescopes. Actual field: 4°. Includes coated, achromatic objective lens and crosshair eyepiece. Precise push-pull focusing. Thousands now in use. Bracket, with collimation screws and lock-nuts, included. Bracket fits all tubes 6″ to 12½″. **$24.50 ppd.**

16— **6 × 30mm RIGHT-ANGLE VIEWFINDER**— **Model 633:** As in (15), but with prism for convenient right-angle observations. Prism may be rotated 360° for maximum viewing comfort. 2-ring bracket included. **$29.50 ppd.**

17— **SERIES 1 KELLNER EYEPIECES (1¼″ O.D.)**—High-quality, fully-coated optics housed in chromed barrels threaded for filters. Sold elsewhere for $18.00 to $22.00. **KE 9, 25, 40mm** .... each **14.75 ppd.**

18— **SERIES 1 ORTHOSCOPIC EYEPIECES (1¼″ O.D.)**— Well-corrected 4-element designs, fully coated, threaded for filters. Sold elsewhere for $26.00 to $30.00. **OR 4, 6, 9, 12.5, 25mm** .... each **$23.75 ppd.**

19— **SERIES 2 MODIFIED ACHROMATIC EYEPIECES (1¼″O.D.; MULTI-COATED)**—Custom 3-element designs, precisely corrected for chromatic and spherical aberrations. Finest obtainable under $20.

FOCAL LENGTHS: MA 6,9,12,25mm, 40mm Wide-Field, ea. $18.95 ppd.

20— **MODIFIED ACHROMATIC 40mm EXTRA-WIDE-FIELD EYEPIECE (1¼″ O.D.; MULTI-COATED)**—Yields widest field obtainable in 1¼″ O.D. Enlarged field lens and special field-flattening optics with long eye relief. **$27.50 ppd.**

21— **SERIES 2 ORTHOSCOPIC EYEPIECES (1¼″ or .965″ O.D.; MULTI-COATED; PARFOCAL)**— The excellent 4-element high resolution optics of these oculars are all the majority of serious amateurs ever require. Razor sharp 45° fields. Both 1¼″ and .965″ O.D. sets parfocalized.

FOCAL LENGTHS: OR 4, 6, 9, 12.5, 18, and 25mm .. each $27.50 ppd.

22— **RESEARCH-GRADE ORTHOSCOPIC EYEPIECES (1¼″ O.D.; MULTI-COATED; PARFOCAL)**—The largest selling premium-quality eyepieces in the world, universally acclaimed to be the finest eyepieces obtainable. 4-element systems, unsurpassed in color correction, resolution, and flatness of field. 45° field. **OR 4, 7, 10.5, 16.8, 28mm** .... **each $42.50 ppd.**

23— **RESEARCH-GRADE ERFLE EYEPIECES (1¼″ O.D.; MULTI-COATED; PARFOCAL)**— For breathtaking wide-angle observations. 65° fields, parfocalized with our Research-Grade Orthoscopics.

FOCAL LENGTHS: ER 7, 12.4, 15.5, 20mm .... **each $47.50 ppd.**

VIEWFINDERS— With helical focusers for ultraprecise control of image sharpness. Coated, achromatic objectives of new Meade design yield fully corrected images throughout the field. Actual field on 50mm models: 4¼°; on 60mm models: 3½°. Crosshair eyepiece, dewcap, dustcap included.

24— **8×50mm—$46.50 ppd.** Brackets: **$9.75/pr. ppd.**
25— **8×50mm RIGHT-ANGLE—$53.50 ppd.** Brackets: **$9.75/pr. ppd.**
26— **GIANT 9×60mm—$65.00 ppd.** Brackets: **$12.50/pr. ppd.**
27— **GIANT 9×60mm RIGHT ANGLE—$71.50 ppd;** Brackets: **$12.50/pr.**

28— **RESEARCH-GRADE ERFLE 32mm EYEPIECE (2″ O.D.; MULTI-COATED)**—Wide-angle, fully-corrected 65° field. The finest eyepiece obtainable in 2″ barrel. **$99.50 ppd.** Adapter Barrel for 1¼″ O.D. **$10.75 ppd.**

29— **DELUXE CAMERA ADAPTERS**— Adapt your camera to telescope focuser instantly. Individually machined from solid bar aluminum and brass. All units permit both eyepiece-projection and first (prime) focus photography. Specify your camera brand and either 1¼″ or .965″ focuser. All 1¼″ units are *threaded for filters.* **Nikon, Canon, Minolta, Pentax K, Konica, Olympus OM, or Universal Thread-Mount** .... **$29.50 ppd.**

30— **2X and 3X TELENEGATIVE AMPLIFIERS (1¼″ O.D.; MULTI-COATED)**— Warranted without qualification to be the world's finest Barlow lenses. Full 26mm clear apertures, Multi-Coated, with virtually flawless optical corrections at all photo-visual wavelengths on any telescope. **2X Model 122:** .. **$29.50 ppd.; 3X Model 123: . . . $32.50 ppd.; 2X Model 131:** Per Model 122, but for .965″ focusers; 18mm clear aperture, Multi-Coated. **$22.50 ppd.**

31— **2X-3X VARIABLE TELENEGATIVE AMPLIFIER (1¼″ O.D.; MULTI-COATED)**— **Model 127:** Made to same research standards as Model 122 above, but mounted in a machined sliding cell, for variable power settings between 2X and 3X. Engraved scale indicates power. Multi-Coated . . . **$39.95 ppd.**

32— **PARABOLIC MIRRORS**— The very finest. 1/10-wave, diffraction-limited primary mirrors. Aluminized and quartz overcoated. Immediate shipment. **6″f/8 . . . $65.00 ppd.; 6″ f/5 . . . $75.00 ppd.; 8″ f/6 . . . $95.00 ppd. 10″ f/6 . . . $195.00 ppd.; 12½″ f/6 . . . $335.00 ppd.**

33— **SECONDARY MIRRORS**— Elliptical 1/10-wave flats. Aluminized and overcoated. Immediate shipment. **1.30″ M.A. . . . $12.00 ppd.; 1.52″ M.A. . . . $16.00 ppd.; 1.83″ M.A. . . . $19.50 ppd.; 2.14″ M.A. . . . $23.00 ppd.; 2.60″ M.A. . . . $27.50 ppd.; 3.10″ M.A. . . . $47.50 ppd.**

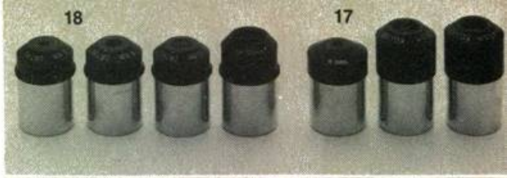
34— **ILLUMINATED RETICLE GUIDING EYEPIECE (1¼″ O.D.)**— New phosphorescent etched double-line reticle permits line illumination from dim to extremely bright. Remote brightness control and 6 ft. cable. Modified Achromatic 12mm optical system. Precisely focusable reticle. Complete . . . **$49.95 ppd.** Interchangeable barrel for .965″ O.D. . . . **$7.50 ppd.**

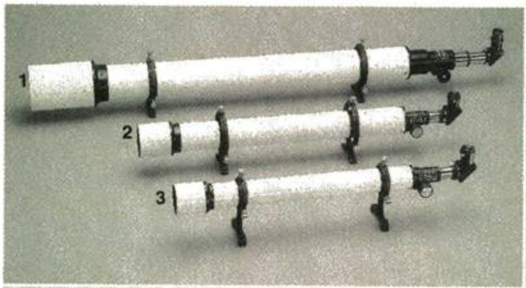
35— **MICROMETER RETICLE**—Full-field scale for accurate measurements of double star separations, planetary angular diameters, etc. Interchanges with standard 4-line reticle of Item (34), above . . . **$19.50 ppd.**

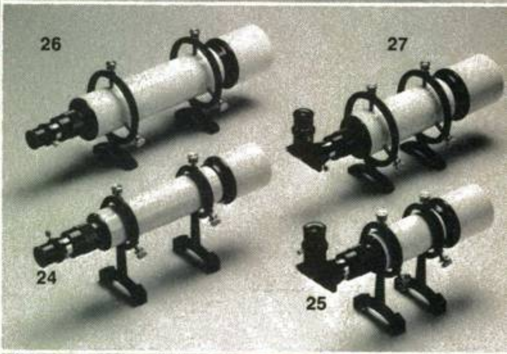
36— **ERECTING PRISMS**— Fully coated Porro prisms. Invert the astronomical image for terrestrial observations with astronomical telescopes. **1¼″ O.D. . . . $29.75 ppd.; .965″ O.D. . . . $25.75 ppd.**

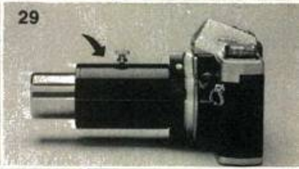
DIAGONAL PRISMS— Optical-quality right-angle prisms, fully coated.

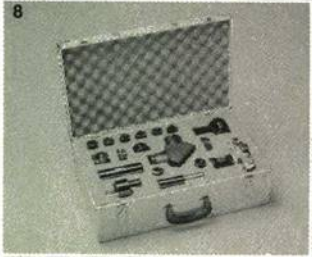
37— **Model 915:**	Fits .965″ focusers, accepts .965″ eyepieces	**$16.95 ppd.**
38— **Model 917:**	Hybrid diagonal— fits .965″ focusers, accepts 1¼″ O.D. eyepieces	**$26.95 ppd.**
39— **Model 918:**	18mm clear aperture. Fits 1¼″ focusers, accepts 1¼″ eyepieces	**$22.95 ppd.**
40— **Model 918A:**	30mm clear aperture. Fits 1¼″ focusers, accepts 1¼″ eyepieces. Enlarged aperture increases field at low power	**$26.95 ppd.**

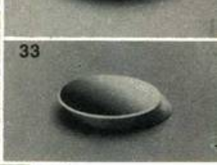


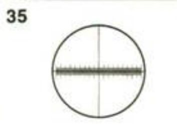


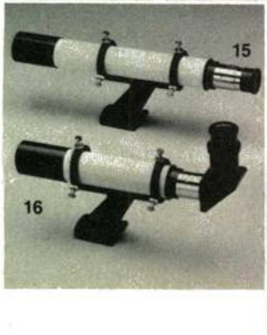


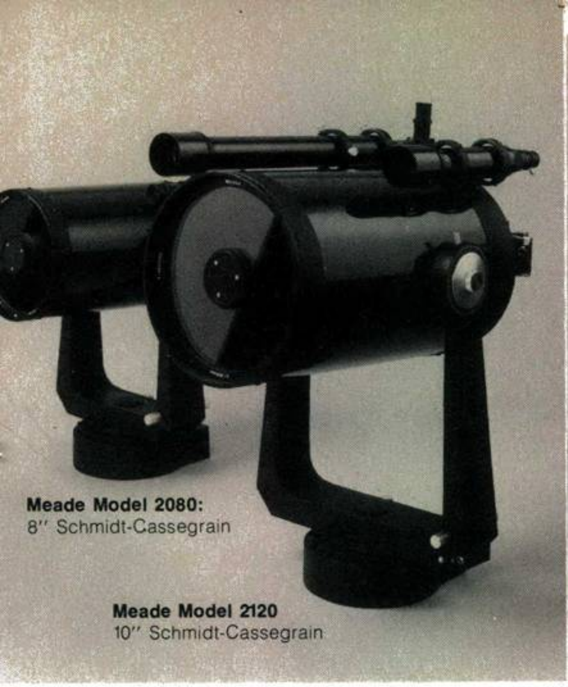




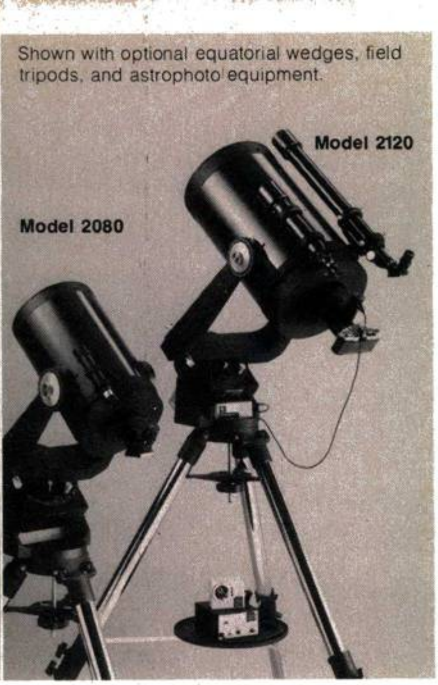







Meade Model 2080:
8″ Schmidt-Cassegrain

Meade Model 2120
10″ Schmidt-Cassegrain


Shown with optional equatorial wedges, field tripods, and astrophoto equipment.

Crown Optics breaks the price barrier on the World's finest 8″ and 10″ Schmidt-Cassegrains. Order the renowned Meade Model 2080 or superb new Model 2120 from us and save hundreds of dollars off the list price:

Meade Model 2080 8″ Schmidt-Cassegrain— This is the telescope that is revolutionizing modern amateur astronomy and astrophotography. Supplied complete as shown with: ball-bearing fork mount, motor drive, 6 ft. power cord, dual slow motion controls, setting circles, 6 x 30mm viewfinder, diagonal prism, luggage-quality carrying case, and 2 multi-coated Modified Achromatic eyepieces (9mm and 25mm), dust covers, instruction manual **$739.95**

Meade Model 2080C 8″ Schmidt-Cassegrain— Identical in all specifications to the Model 2080 above, but with 2 fully-coated Kellner eyepieces (9mm and 25mm) in place of the Modified Achromatic eyepieces, and with rugged foam-lined gift carton packing substituted for the carrying case **$699.95**

Meade Model 2120: 10″ Schmidt-Cassegrain— Over 56% more light-gathering power than 8″ models. Complete with ball-bearing fork mount, motor drive, 6 ft. power cord, dual slow motion controls, setting circles, 8 × 50mm viewfinder, diagonal prism, luggage-quality carrying case, and 2 multi-coated Modified Achromatic eyepieces (9mm and 25mm), dust covers, instruction manual **$1779.00**

Telescopes are a full-time business with us. Both before and after your purchase our highly qualified staff of 23 technical, order-desk, and shipping personnel are available Mon. - Fri. 8:30 - 5:00 to answer your questions, whether concerning an anticipated order or the use and application of a telescope or accessory you have already received.

PRICE LIST

MEADE MODEL 2080: 8″ SCHMIDT-CASSEGRAIN TELESCOPE	Base price, complete	**$ 739.95**
MEADE MODEL 2080C: 8″ SCHMIDT-CASSEGRAIN TELESCOPE	Base price, complete	**699.95**
MEADE MODEL 2120: 10″ SCHMIDT-CASSEGRAIN TELESCOPE	Base price, complete	**1779.00**
Meade Equatorial Wedge for 2080/2080C		**50.00**
Meade Equatorial Wedge for 2120		**80.00**
Meade Variable-Height Field Tripod for 2080/2080C/2120		**135.00**
Meade High Transmission Coating for 2080/2080C		**70.00**
Meade High Transmission Coating for 2120		**110.00**

All prices include packing. F.O.B. Costa Mesa, Calif.

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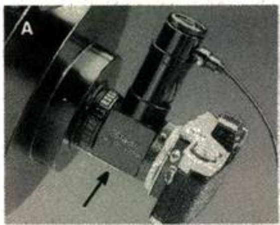
Research-Quality Accessories for Meade and Celestron Schmidt-Cassegrains

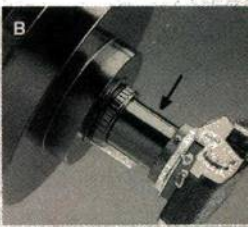
All of these Meade accessories are of the finest optical and mechanical quality available, and all (except item H) may be used interchangeably on Meade and Celestron Schmidt-Cassegrains.

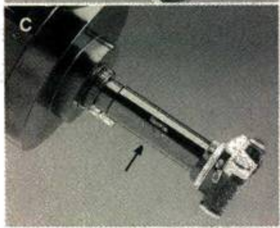
PRICE LIST

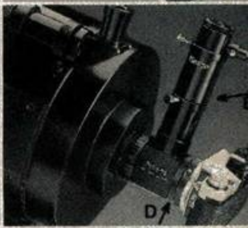
A—	**Off-Axis Guider Body**	**$45.50 ppd.**
B—	**T-Adapter**	**19.00 ppd.**
C—	**Tele-Extender**	**19.00 ppd.**
	T-Rings (specify camera brand)	each **10.00 ppd.**
D—	**Telecompressor Lens** (f/5), Multi-Coated	**37.50 ppd.**
E—	**Extender Tube** (to use Telecompressor with Off-Axis Guider)	**11.50 ppd.**
F—	**Wide-Field Adapter Systems** (Visual Telecompressors) Includes Telecompressor Lens, Special T-Adapter, and Diagonal Prism.	
	For .965″ eyepieces	**71.50 ppd.**
	For 1¼″ eyepieces	**77.50 ppd.**
G—	**2″ Diagonal Mirror.** Includes adapters for 1¼″ and 2″ O.D. eyepieces	**159.95 ppd.**
H—	**Dual-Axis Drive Corrector, Model 46**— Attaches in 2 minutes to Meade Models 2080, 2080C or 2120. No drilling required. Includes R.A. drive corrector, Dec. motor and clutch system, joystick controller. Operates from 115v. /60Hz or 12v.D.C.	**219.50 ppd.**
I—	**Solar Filters**— Optical glass, Inconel-coated, for professional-level solar observation. For Meade 2080 or Celestron 8.	
	#955: 8″ Full-Aperture Solar Filter	**165.00 ppd.**
	#956: 3″ Off-Axis Solar Filter	**90.00 ppd.**
J—	**Series 6 Drop-In Filters** (not shown). Optical glass. Includes Pink, Yellow, Yellow-Green, Red, Blue, Neutral (0.6). Set of 6 filters	**35.00 ppd.**

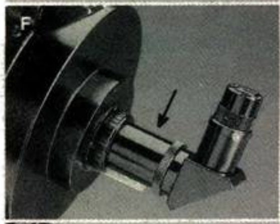
For Nebular Filters, Thread-In Filters, Drive Correctors, Barlow Lenses, Illuminated Reticle Eyepieces, and Erecting Prisms, see the accessories listing on the facing page. These accessories are fully compatible with Meade and Celestron Schmidt-Cassegrains.

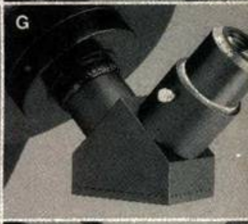












Toll-Free Phone-Order Desk for VISA and Master Card Holders or for C.O.D. Orders, dial

800-854-7485 (orders only)

from anywhere in the continental U.S.A., except California. Order Desk Hours: 8:30 - 5:00 Pacific Time Monday through Friday

For General Information, or to place orders from all other geographical areas, dial direct (not collect): **714-966-1200**.

ORDERING INFORMATION

1. **Mail and Phone Orders only!** No dealer sales.
2. **Payment.** Personal or bank check, money order, VISA, or Master Card. (Immediate shipment on complete telescopes requires payment by cashier's check, M.O., or credit card.)
3. **All orders** are financially guaranteed by Meade Instruments Corporation.
4. **All products** are brand-new (no "seconds"!) and are normally available for immediate shipment.
5. **Within the U.S.A.:** Shipment by United Parcel Service direct to your door, fully insured, safe arrival guaranteed. **Canadian Orders:** See our Order Form for further details.
6. **All products** carry the Meade Instruments Full-Year Limited Warranty, and are backed by the Crown Optics reputation for trust and fair-dealing with our customers.
7. **California residents:** Add 6% Sales Tax.
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photography in astronomy

focus on luna

When a novice stargazer's thoughts turn to astrophotography, the Moon is frequently the first target that comes to mind. Luna is so big and bright that most of us are tempted to turn whatever camera we have toward her shining face, hoping to record some semblance of an image on film.

Your first results may end up faint and fuzzy, but the basic technique that produces a flawed image only needs refinement for more successful lunar photography. Any combination of lenses, telescopes, or cameras will yield satisfactory results as long as you realize the equipment's limitations.

Whether you use a wide-angle lens on a 35mm camera to record the Moon's passage against a starry field, or eyepiece projection through a Cassegrain scope for detailed portraits of small craters, you'll end up with a pleasing image of our nearest celestial neighbor.

The size of the lunar face on film depends on the focal length of the lens. If you're only interested in close-ups of craters, it doesn't make sense to use a wide-angle lens and then enlarge the picture in the darkroom — you'll still end up with a small dot for a Moon. So first decide what kind of lunar portrait you want, bearing in mind your level of astrophotographic expertise.

The great thing about the Moon is that you can photograph it from any level of sophistication. If you're just starting out, try a simple unguided exposure of the Moon rising above your neighborhood. Set your camera on a tripod with its 50mm lens wide open and focused at infinity and make a series of exposures from 1/125 second to three seconds. Don't be afraid to use the whole roll of film. The experience you gain from seeing the effect of different exposures will save you from wasting film later. You'll also see the size of the Moon on the finished print or slide, and then you'll know that a 50mm lens produces a lunar image only 1mm in diameter — too small for studying detail. But you'll have discovered that this set-up yields excellent pictorial results, and might work well for conjunctions or other wide-field applications.

You can use this same tripod-mounted method with lenses up to 500mm, and each increase in focal length produces a correspondingly larger and more detailed Moon. For most lenses the exposures will stay within the same range as above, but you might want to extend the time to 10 seconds with longer telephotos.

Dramatic pictures of the rising or setting Moon, "the new Moon in the old Moon's arms," eclipses, and detailed conjunction or occultation photographs are easy with medium to long telephoto lenses. Just remember that with more magnification, gremlins like atmospheric turbulence, camera vibration, and wind amplify the problems of taking a crisp, sharply focused picture.

If your longest telephoto still doesn't give you the image size you want, you'll have to use a camera-telescope combination. You have four methods available to take pictures through a telescope: prime focus, afocal, eyepiece projection and negative projection (see "Photograph the Moon," ASTRONOMY, February 1978).

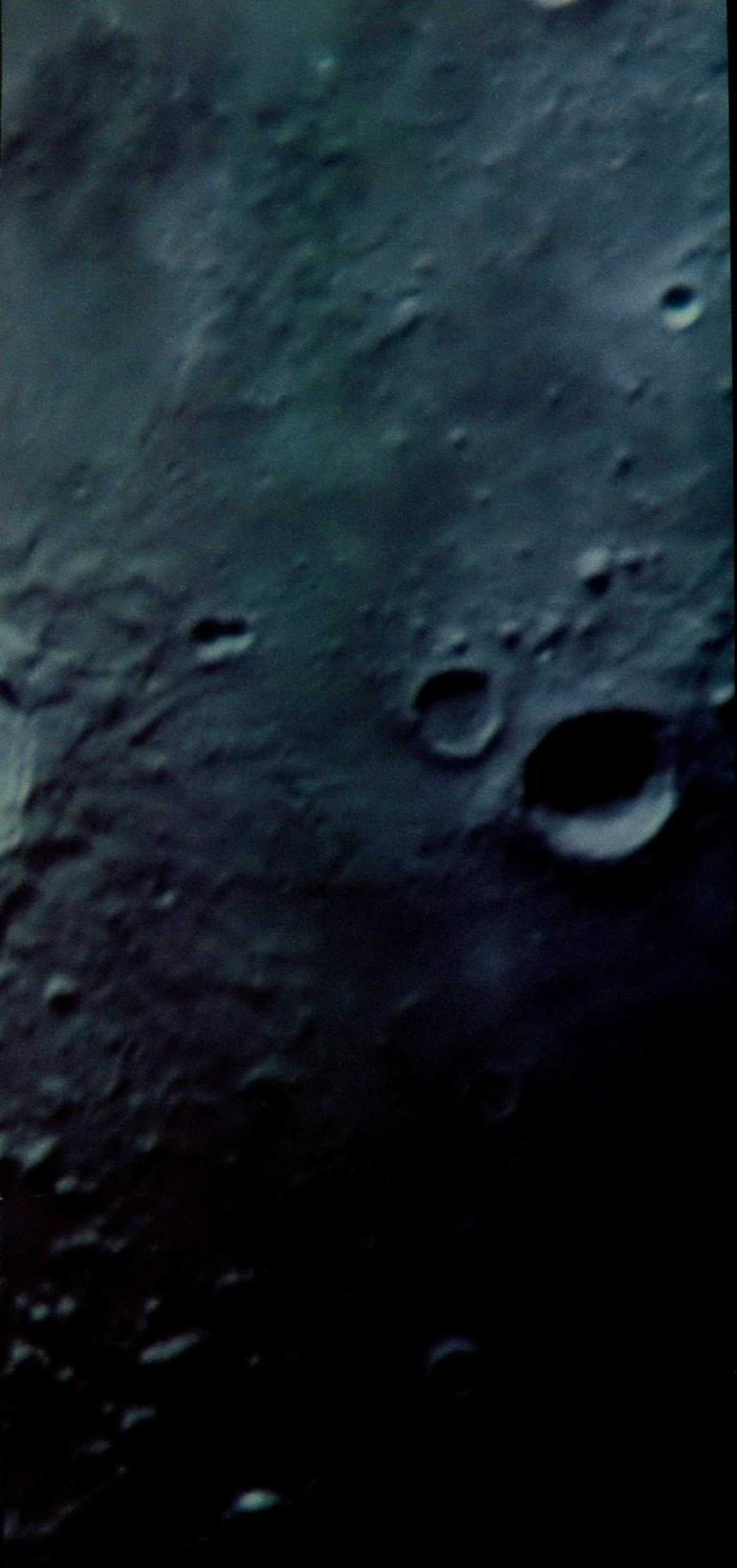
The *prime focus* method involves coupling your camera with some type of adaptor to the eyepiece drawtube. You now have a huge telephoto lens. If your telescope is a 6-inch f/8, then it produces a lunar image on film about half an inch in diameter, with the larger craters and maria standing out vividly. Depending on the speed (ASA) of the film you're using, and the phase of the Moon, you'll want to set your exposures between 1/125 second and 3 seconds. Of course, the Full Moon is 10 times brighter than a crescent, so your exposures will increase as the size and brightness of the Moon decreases.

The prime focus method is best for showing full disk views of the Moon's different phases, or occultations with brighter planets or stars. Since the image size on the film is bigger than with a telephoto, you can make enlargements that show even more features, but you still haven't taken the most detailed close-ups possible. For true high-resolution work, you'll have to use another technique.

The *afocal* method is an easy way to increase image size. Afocal simply means placing your camera — with its 50mm lens attached — up to the telescope's eyepiece. Depending on what phase the Moon is in, you may want to use a tripod if the camera's meter indicates a shutter speed of less than 1/30 second. Just couple the camera to a tripod and place it so the lens aims into the eyepiece. You might also roll a tube of black construction paper and put it around the lens and eyepiece drawtube to keep out stray light.

With an afocal combination it's easy to calculate the size of the Moon's image on film. Your 50mm lens aimed into a 100-power eyepiece gives you a focal length of 5,000mm. Divide that figure by 115 to give you the size of the lunar disk on film: 43.5mm. The Moon's image will be bigger than the 35mm frame, so you'll record small details. If your scope is a 6-inch (150mm) f/8, the f/ratio will be 5,000 divided by 150 or approximately f/33.

Above: The Full Moon by Ken Owen at the prime focus of his 10-inch f/6 on ASA 12 film and a 1/60-second exposure. Right: A crescent Moon with Earthshine photographed by Jim Rouse at the prime focus of his 8-inch f/7. He needed a 30-second exposure on ASA 200 film to record the dark part of the Moon; his camera has a shutter that can be "locked up" to prevent vibrations.



On a night of superb seeing, Jim Rouse photographed Copernicus. For high-resolution photos, you'll need a steady mounting and flawless technique. A 2-second exposure at f/54 through a 14-inch Schmidt Cassegrain recorded this magnificent portrait. You have to practice to produce a shot this good.

Use the table on page 54 to determine a good starting point for trial exposures.

Negative projection is similar to prime focus except that you use a Barlow lens to increase the size of the Moon's image. This is the simplest way to produce more detailed shots, but the inherent lack of sharpness in many Barlows will only hinder your attempts at accurate focusing.

Instead, for those really detailed pictures of single craters or mountain chains, try *eyepiece* or *positive*

which films to use?

You can use any film for photographing the Moon, but keep in mind the characteristics of the type you choose. Both black-and-white and color emulsions work fine for Moon photos, and you don't need to use use fast films because the Moon is amply lit by sunlight.

If you have a home darkroom, start with black-and-white since you'll be able to process it yourself and correct any under or over-exposure when you print the negative. (See "Improving Your Lunar Photographs," ASTRONOMY, November 1977.) Good B&W films include Kodak Plus-X (ASA 125) or Ilford FP-4 (ASA 100) for crescent phases, or Kodak 2415 for the Full or gibbous phases. Make sure you pick a fine grain film with an ASA less than 200.

The choice is harder for color. Kodachrome 25 (ASA 25) offers the finest grain, but it is too slow for all phases except Full. Kodachrome 64 is the next best and should work well for most phases, but you'll have to use slightly longer exposures. The best all-purpose film might be Ektachrome 200, combining relatively fine grain with an acceptable speed. You can keep exposures short and minimize the effects of vibration or atmospheric turbulence with this film, so until you gain experience use Ektachrome 200.

When you have color film processed commercially, remember to shoot a non-astronomical object with either the first or last frame so the lab's automatic film cutting machines know where the frame begins.

One final word about choosing a film for lunar photography. Once you've made up your mind, stick with that film until you're entirely familiar with it. Don't switch to the newest wonder film from week to week. If you keep records of your exposure times and then compare them with the finished results, you'll be able to quickly prepare a chart of exposures that will work every time with the equipment you own.

lunar exposures

	Film ASA	Full	Gibbous	Quarter	Crescent	Thin Crescent
f/5	25	1/125	1/60	1/30	1/15	1/8
	50	1/250	1/125	1/60	1/30	1/15
	100	1/500	1/250	1/125	1/60	1/30
	200	1/1000	1/500	1/250	1/125	1/60
f/7	25	1/60	1/30	1/15	1/8	1/4
	50	1/125	1/60	1/30	1/15	1/8
	100	1/250	1/125	1/60	1/30	1/15
	200	1/500	1/250	1/125	1/60	1/30
f/10	25	1/30	1/15	1/8	1/4	1/2
	50	1/60	1/30	1/15	1/8	1/4
	100	1/125	1/60	1/30	1/15	1/8
	200	1/250	1/125	1/60	1/30	1/15
f/15	25	1/15	1/8	1/4	1/2	1
	50	1/30	1/15	1/8	1/4	1/2
	100	1/60	1/30	1/15	1/8	1/4
	200	1/125	1/60	1/30	1/15	1/8
f/22	50	1/15	1/8	1/4	1/2	1
	100	1/30	1/15	1/8	1/4	1/2
	200	1/60	1/30	1/15	1/8	1/4
	400	1/125	1/60	1/30	1/15	1/8
f/32	50	1/8	1/4	1/2	1	
	100	1/15	1/8	1/4	1/2	1
	200	1/30	1/15	1/8	1/4	1/2
	400	1/60	1/30	1/15	1/8	1/4
f/50	100	1/8	1/4	1/2	1	
	200	1/15	1/8	1/4	1/2	1
	400	1/30	1/15	1/8	1/4	1/2
f/70	100	1/4	1/2	1		
	200	1/8	1/4	1/2	1	
	400	1/15	1/8	1/4	1/2	1
f/100	100	1/2	1			
	200	1/4	1/2	1		
	400	1/8	1/4	1/2	1	

For high-resolution lunar photography, use eyepiece projection. Steve Reed photographed the Moon's southern region at f/44 with an 8-inch scope projecting through an 8mm eyepiece. He used a 2-second exposure on ASA 200.

projection. This method is the trickiest since the magnification is greatest and any amount of vibration will destroy the fine focus necessary for high-resolution work.

Just pick an eyepiece of moderate power, say 18mm, and attach the camera without a lens to the telescope tube in a position so the focused image out of the eyepiece falls on the film plane. You'll have to do a bit of experimenting until you find the best spot for the camera. Once you do, tighten the camera securely so it won't sag during the exposure. Again, a short tube of black construction paper will prevent any light from fogging the film while the shutter is open. If you plan on using eyepiece projection frequently, invest in a set of adaptor tubes so you'll be able to rigidly couple your camera to the eyepiece. Both Edmund Scientific and University Optics offer these.

Since eyepiece projection gives maximum image scale, you'll want to calculate the size that the Moon will be on the film. If you're using a 18mm ocular with a throw of six inches (150mm), then the image magnification is roughly 150 divided by 18 or 8.3 times.

With your 6-inch f/8, the focal length is 48 inches, and the focal length of the entire system is 9,960mm. The Moon's diameter will then be 9,960 divided by 115, or 86mm; the f/ratio is 9,960 divided by 150 (6 inches) or nearly f/70. Check the table for a suitable exposure.

Now you have all the possible methods for photographing the Moon, but your final image of the Moon will only be as good as the weakest link in the entire chain. If the atmosphere is turbulent the moment you open the shutter, there isn't a thing you can do about it. One way to get around this aggravating problem is to take many pictures one after the other to guarantee that the atmosphere will be calm for at least one. And remember to re-focus carefully after each exposure just in case something slipped out of whack.

If the exposure must be longer than ¼ second, manually lock up your camera's mirror before you squeeze the shutter release to further minimize vibration. Your telescope's mounting also plays a vital role in high resolution lunar photography. Make sure it is stable enough to handle the extra weight of a camera without becoming too wobbly.

Keep all these things in mind, and after shooting a few rolls and getting your feet wet, you're bound to produce a high-quality lunar portrait. Don't be discouraged if your first results aren't as good as you expected — they never are. Keep practicing and soon you'll have a picture suitable for framing.

Just one more caveat. If this is your first attempt at astrophotography, start out with a stationary camera and normal lens — you can get some attractive pictures that way too.

— *Berry Brunk*

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PROBLEM #1 How to locate unfamiliar celestial objects quickly, easily, confidently and comfortably?

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SOLUTION Use the famous Tuthill Solar Skreen, the only filter with a USA patent #3,897,140. For information about its safety, see the article by Dr. B.R. Chou in *Sky & Tel.*, Aug. 1981, page 119, or Astronomy Review, March 1982, pg. 75. No glue or magnets, double aluminum surfaces shielded from damage.

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SOLUTION Use the light-weight Tuthill No Du Caps which fit all scopes. Unheated or heated and attach without tools.

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Celestron offers many excellent oculars to increase the performance of your Celestron or other telescope. Celestron Erfles in the 16, 20, 24, 28 and 32mm focal length (1¼" barrel diameter) are tested for optimized performance with Celestron telescopes. The Celestron Erfles give excellent wide angle performance, with huge apparent fields (larger than most Plossl designs) and large eye relief. The Celestron Erfles are excellent for deep sky work.

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New! Celestron now offers standard on its C8 a 25mm Orthoscopic Ocular—1¼." A very fine ocular! Celestron offers .96" Orthoscopics of 4, 5, 6, 7, 9 and 12mm focal lengths. 2" Dia. 18, 25 and 40mm Orthoscopic oculars and 1¼" Orthoscopics—4, 5, 6, 7, 9, 12, 18, and 25mm.

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Barlow Lenses have been around since the early 1800's. What do they do? They multiply the power of your eyepiece by 2, 2.5 or 3 times depending on which you choose. Celestron Barlow Lenses have large, high quality negative achromats that boost the power of any eyepiece used with them. There are two major benefits you get with Barlow Lenses. (1) You'll effectively multiply the number of eyepieces you have by two; you can use the eyepiece at its normal focal length, of course, and it essentially becomes another eyepiece of half to one-third the focal length when you combine it with one of Celestron's high quality Barlow Lenses (one-half the eyepiece focal length—twice the power—with a 2x Barlow, etc.). (2) Barlow Lenses will give you more eye relief—use an ocular with a Barlow Lens and you'll have more eye relief than with an ocular by itself. This means you can use medium power eyepieces and a Barlow to reach high powers with plenty of eye relief (distance of the eyeball from the eyepiece) an important consideration for observers who must wear glasses to correct eyesight problems.

Of course, you shouldn't use a Barlow Lens to obtain higher than 60 power per inch of aperture with your telescope and still expect perfect definition—there is an upper limit to the magnifying power of any telescope!

Barlow Lenses Available: 2x—.96," 2.5x—.96," 3x—.96," 2x—1¼," 3x—1¼," 2x—2."

PORRO PRISMS (.96," 1¼") AND STAR DIAGONALS (.96," 1¼," 2")

Porro Prism Shown

The Celestron telescopes currently manufactured are all Cassegrains—the light is bounced between two mirrors and exits through a perforation in the primary mirror. This means when you look straight up (as is frequently the case for astronomers), you are observing in a difficult position; because of this Celestron supplies a right angle Star Diagonal with each astronomical telescope. Our Star Diagonals contain anti-reflection coated right angle prisms for distortion-free viewing; eyepieces are held in place with a set screw in all versions, .96," 1¼," 2." The 2" diameter diagonal allows the high image fidelity and wide field of view that 2" oculars provide. A 2" diagonal is available for the C5, C8 and C11. The 2" diagonal is a mirror type to provide maximum transmission.

Star Diagonals yield right-side-up but backward images. This can be disconcerting when viewing on the ground. Thus, for terrestrial observations that yield normal views through your Celestron, use a Celestron Porro prism. Now, birdwatching, people watching and sign reading are much easier! .96" for C90's and 1¼" diameter for C5's, C8's, C11's and C14's are available. Both use set screws to attach an eyepiece.

CELESTRON ACCESSORIES MAKE YOUR TELESCOPE

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Celestron proudly offers a heavy duty photographic tripod for all Celestron spotting scopes, telephotos and astronomical binoculars. The Celestron Photographic Tripod is made of tubular aluminum legs and central column. The Celestron Photographic Tripod is extendible from 24 to 64 inches in height for the utmost in observing comfort. The tripod has the universal ¼-20 mounting bolt so you may use it for any camera, telephoto, spotting scope or binocular that has a tripod adapter block. The all-aluminum tripod is finished in a handsome black anodize so that it is well protected from the environment and distinctive in design. Separate pan, tilt and elevation controls provided.

Use the Celestron Photographic Tripod for constellation photography with your camera or for supporting a large pair of binoculars. The stability and comfort you gain when using our large binoculars with the Celestron Photographic Tripod will more than double your enjoyment of them and their ease of use!

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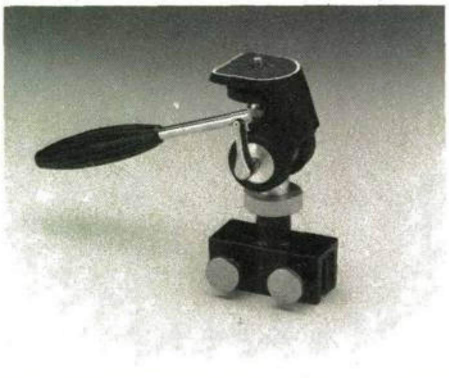

Although you can't do much astronomy from your car, you often can better observe animals and wildlife from your car. For the proper support of Celestron Classical and Giant Series Binoculars, Celestron Spotting Scopes and Celestron Telephoto Lenses consider the Celestron Car Window Mount. This window mount has a ¼x20 universal mounting screw so you can use it to secure cameras and any other product with a ¼x20 tripod mounting block.

The Car Window Mount has a 2¾" long vise-like grip section that firmly attaches to your car window and is secured with two oversize locking screws with large knurled knobs. The tilt control is locked by a conventional tripod grip control; the pan adjustment is secured by a contoured quick release locking latch. The entire car window mount has been designed to provide a sturdy support for your binoculars/spotting scopes/telephoto lens in a compact, functional design that's easy to operate in the sometimes cramped operating conditions of your car.

LAR AND EXPANDING/REDUCING BUSHINGS

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ACCESSORIES

EYEPIECE FILTER SETS AND POLARIZING FILTER SETS (.96," 1¼," 2" SIZES)

Polarizing Filter Set—1¼" Shown

If you observed the planets this summer you've no doubt noticed that picking out faint details was sometimes difficult because of low contrast and lots of glare. Whenever you observe a small bright object you can decrease glare by using a polarizing filter. Polarizing filters are available for lunar, planetary and double star work from Celestron in .96," 1¼" and 2" sizes. Each Polarizing Filter **Set** has two polarizers and a filter adapter. When the two polarizers are used together you have a variable density, neutral density filter.

To bring out faint color markings on planets use the Eyepiece Filter Sets. Celestron manuals make specific recommendations on which filters to use. The Eyepiece Filter Sets also help to observe lunar details and are available in .96," 1¼" and 2" diameters, in a boxed set of six (neutral density, green, orange, violet, blue and yellow).

COUNTERWEIGHT SETS

Counterweight Bar—8" Shown

When you use heavy visual or photographic accessories it is helpful to balance your telescope for ease of operation and correct clock drive action. Celestron telescopes, because of their symmetrical fork mounts are easily counterbalanced with our counterweight sets:

Counterweight Set—5/90

This is a set of 4 weights that clip onto the front cell of the C90 or the C5. Attach the clip and add whatever weight is necessary to balance your Celestron as well as possible (a slight imbalance is normal, even preferable in the east-west direction).

Counterweight Set—8"

This set of 6 weights threads into special receptacles in the front cell of the C8. This set is normally used to balance small accessories such as a camera and T-Adapter, a Tele-Extender, a Piggyback-mounted camera, etc.

Counterweight Bar Assemblies—for the C8 or C11.

These are sliding counterweights and brackets that allow you to balance virtually any accessory you wish to place on your Celestron. One is standard with the C11, two with the C14. Use this for such heavy accessories as a large piggyback camera or a guide telescope.

TELE-CONVERTER

Have you ever wanted to get just a bit more magnification when photographing terrestrial subjects? Now, instead of getting closer, you can use a Celestron Tele-Converter to shrink the distance between you and your photographic quarry. Place the Tele-Converter between your camera's T-ring and the T-adapter and you'll boost your photographic power by 2 to 3 times! These Tele-Converters are essentially photographic Barlow Lenses and they have been tested to assure good results with Celestron telescopes and telephotos. Due to the positioning of the Tele-Converter you get a different magnification factor when you use it with different Celestron lenses:

CELESTRON LENS	APPROXIMATE MAGNIFICATION
300mm	2.5x
500mm	2.7x
750mm	2.5x
1000mm (C90)	3x
1250mm (C5)	2x
2000mm (C8)	2.4x

MORE ENJOYABLE AND EXPAND ITS CAPABILITIES

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equipment atlas

astronomy in the garden

by Edmund A. Fortier

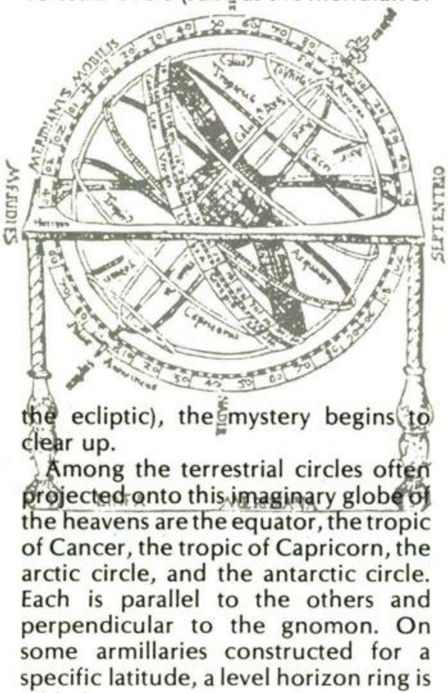
For millennia sundials were the world's timekeepers. Simple in design and easy to make, they were sufficiently accurate for most people's needs and, as long as the Sun was shining, dependable. From crude beginnings sundials evolved into precise scientific instruments by the time of the Renaissance. In addition to marking the hours, they could show the time of sunrise and sunset, the day of the year, and the declination of the Sun.

But these improvements — fostered by the needs of a culture that had newly become time-conscious — were still not enough. By around 1500, the first reliable mechanical clocks began to dominate time keeping, and the sundial was largely relegated to ornamenting gardens. And there it remains today, a unique astronomical instrument, seldom used and rarely understood.

But sundials have applications beyond telling time, so we have several good reasons to rescue them from obscurity. When properly set up, a sundial graphically demonstrates a number of principles fundamental to astronomy. And while this is true of virtually all dials, one type in particular — the armillary sphere — is especially suited for this purpose. Devised over 2,000 years ago by the Alexandrian astronomer and mathematician Eratosthenes, the armillary is a versatile educational tool. Understanding the design and correct use of this elegant instrument amounts to a primer on the celestial sphere.

In essence, an armillary sphere is a model of the universe as the ancients saw it: a hollow globe with the Earth at its center. Constructed as an open sphere of rings — their name comes from the Latin *armilla,* meaning ring or bracelet — their outer sphere represents the heavens. In most, a globe of the Earth was affixed to the center of a thin rod called the *gnomon* that passed through the rings and which corresponded to the Earth's axis. The armillary was an elaboration of the equatorial sundial originally intended to depict a pre-Copernican universe. It can still be used as such if the model of the Earth is removed from its center — the modified form we find most often today.

Armillaries come in a variety of sizes and configurations. Some are simple and consist of only two or three rings, while others are complicated affairs of many rings. At first glance, the more intricate armillaries look bewildering, but when you understand that each ring represents a major terrestrial or celestial circle (such as the meridian or the ecliptic), the mystery begins to clear up.



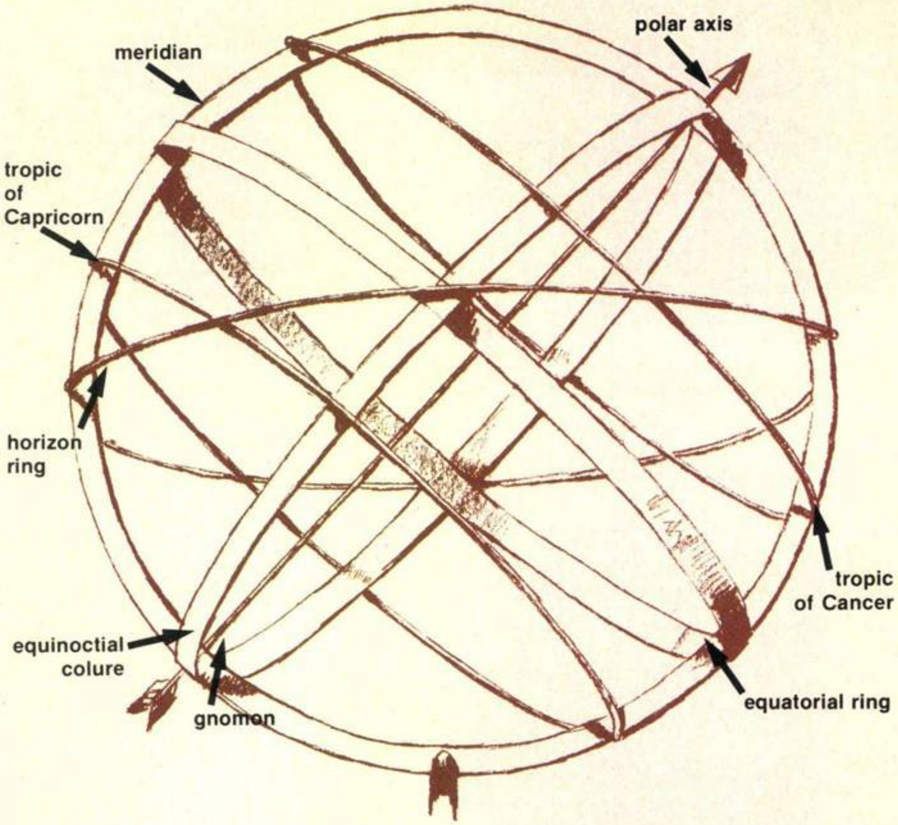
Among the terrestrial circles often projected onto this imaginary globe of the heavens are the equator, the tropic of Cancer, the tropic of Capricorn, the arctic circle, and the antarctic circle. Each is parallel to the others and perpendicular to the gnomon. On some armillaries constructed for a specific latitude, a level horizon ring is added.

Of the celestial circles, the meridian and ecliptic rank highest and appear most frequently on armillaries. The ecliptic is inclined 23° 27′ to the equatorial band and extends as far north as the tropic of Cancer and as far south as the tropic of Capricorn, the points of the Sun's greatest northern and southern declination. Many armillaries, for aesthetic as well as mechanical reasons, include a ring that denotes the *equinoctial colure* — a circle that passes through the north and south celestial poles and the points where the ecliptic crosses the equator.

Both seasoned skywatchers and novices can learn much from an armillary. Because it has three dimensions, you can view the celestial sphere from different perspectives and avoid the distortions inherent in two-dimensional maps. When used as a sundial, an armillary is an introduction to the daytime sky — although you'll need an understanding of how apparent solar time differs from clock time to obtain accurate time readings. At night, the armillary also serves as a basic reference guide since its major rings parallel their celestial counterparts.

To use an armillary as a sundial, you must first point it toward the pole — just like a telescope, an armillary must be polar-aligned. As the Earth rotates, the Sun will appear to revolve east to west around the gnomon once a day. The shadow cast by the gnomon on the inner surface of the equatorial band indicates the hour. Since the Earth rotates once every 24 hours, the shadow transverses 15° each hour. Hours are inscribed on the band at 15° intervals from the 12 o'clock line — morning hours to the west of the gnomon, afternoon hours to the east.

There is one practical problem with armillaries-as-sundials: around the equinoxes, the Sun lies close to the celestial equator. This means the shadow of the upper part of the equatorial band will fall on the lower part — and you won't be able to see the shadow of the gnomon. Fortunately, the period of total obscuration lasts only about a few days



at each equinox.

The easiest way to align an armillary is first to adjust the gnomon to the correct latitude and then orient it along the meridian. A local surveyor, library, or town hall can provide your latitude or U.S. Geological Survey topographic maps from which you can determine it. While you're looking, get your longitude as well; you'll need it later. If you purchase an armillary, be sure it has a "universal" base — one that lets you adjust the gnomon to any latitude.

Now you have to align the sphere north. If you use a compass, be sure to *allow* for the difference between magnetic north and true north — the deviation will be shown on the topographic map for your location. Or you can simply sight in on Polaris.

Yet another simple method is to place a flat, level board with a vertical gnomon — such as a nail — where the armillary will sit. Draw several concentric circles with a compass, using the gnomon as the center. Mark where the shadow of the gnomon first touches one of the circles in the morning and again where it first touches the same circle in the afternoon. Without moving the board, connect these two points with the center of the circles; a line bisecting the resulting angle will be your meridian line. Fix the armillary securely in place and you're all set.

Now, if you compare your watch with the time indicated by the shadow of the gnomon, you'll probably notice a difference. Sun time differs from clock time for two reasons. First, the Sun's rate of travel along the celestial equator isn't uniform — it varies over the year because the Earth's orbit is not a circle, but an ellipse. On any day, the Sun may be faster or slower than your watch, which measures out a uniform or mean time. The difference between apparent solar time and mean solar time is called the "equation of time" and average values for it are tabulated in the box below.

The second reason for the discrepancy is that few people live exactly on the standard longitude for their time zone: Eastern is 75°W, Central 90°W, Mountain 105°W, Pacific 120°W, and Alaska/Hawaii 150°W. If you live east of your zone's standard longitude, the Sun reaches noon at your location before it reaches noon at the standard longitude — thus your sundial is fast. Likewise, when you live west of the standard zone longitude, noon for you happens late — your dial is running slow.

Unlike the equation of time, the correction for longitude is simple because it remains constant throughout the year. Just work out the difference between your longitude and the standard for your time zone. For every degree they differ, the sundial-time is incorrect by four minutes. With the difference in minutes worked out, add it to what the dial says if you live west of the standard zone longitude and subtract it if you live east. Remember to add an hour if daylight saving time is in effect. But one caution: never turn the dial to change the reading — that will disrupt the polar alignment.

A properly aligned armillary is a terrestrial and celestial compass as well as timekeeper. The polar axis marks a true north-south line and points to the north celestial pole. The equatorial band crosses the horizon ring at true east and true west. The meridian ring, when projected onto the sky, coincides with your celestial meridian just as the equatorial ring, projected skyward, marks the celestial equator. On the other hand, the ecliptic ring and equinoctial colure are fixed in place, although they represent celestial circles that in fact rotate with the sky; these features are more decorative than useful.

To the ancients, armillaries and sundials filled aesthetic as well as practical needs. The heavens, vast and immutable, moved with predictable precision, an assurance of their perfection. These devices were a means by which humans, however indirectly, could link themselves with the inaccessible heavens. If the heavens were perfect, a quiet satisfaction could be found by watching that perfection mirrored in the moving shadow of a sundial.

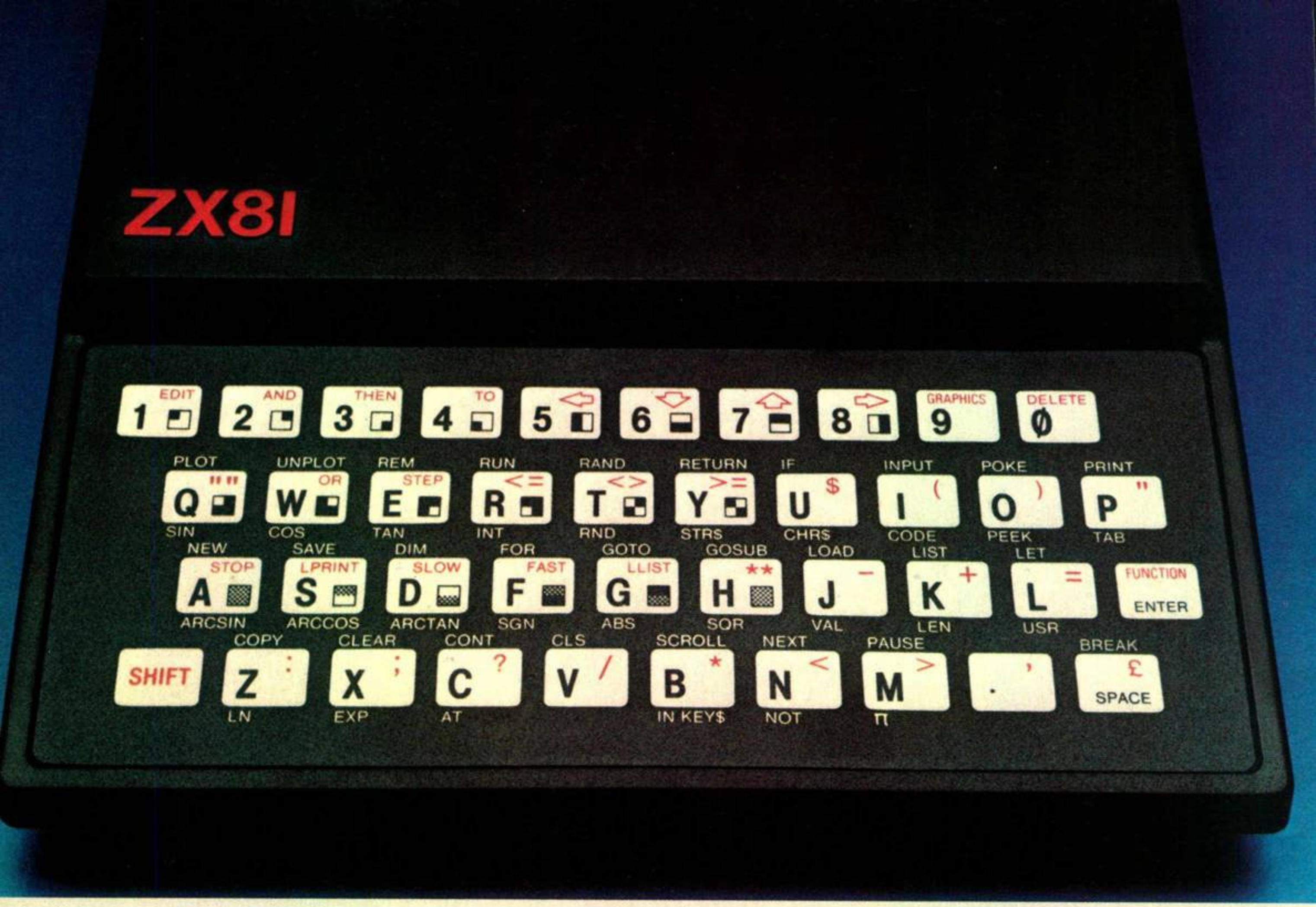
Four hundred years after Copernicus made obsolete the geocentric universe it was intended to represent, the armillary remains a unique garden ornament and a useful teaching tool. And while it may now fill aesthetic and practical needs different from those of the distant past, we can still share with the ancients the satisfaction of tapping into the rhythms that order our lives.

the equation of time

January	1	+3:12	July	1	+3:33
	15	+9:10		15	+5:46
February	1	+13:33	August	1	+6:16
	15	+14:16		15	+4:33
March	1	+12:34	September	1	+0:12
	15	+9:13		15	-4:32
April	1	+4:08	October	1	-10:05
	15	+0:14		15	-14:01
May	1	-2:51	November	1	-16:20
	15	-3:44		15	-15:28
June	1	-2:25	December	1	-11:11
	15	+0:10		15	-5:09

The figures show the minutes and seconds to add to (+) or subtract from (-) the dial.

Edmund Fortier is a high-school teacher in Weymouth, Massachusetts, and has been interested in astronomy all his life.


ZX81
1 EDIT 2 AND 3 THEN 4 TO 5 6 7 8 9 GRAPHICS 0 DELETE
PLOT UNPLOT REM RUN RAND RETURN IF INPUT POKE PRINT
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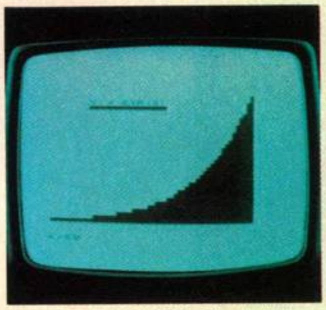

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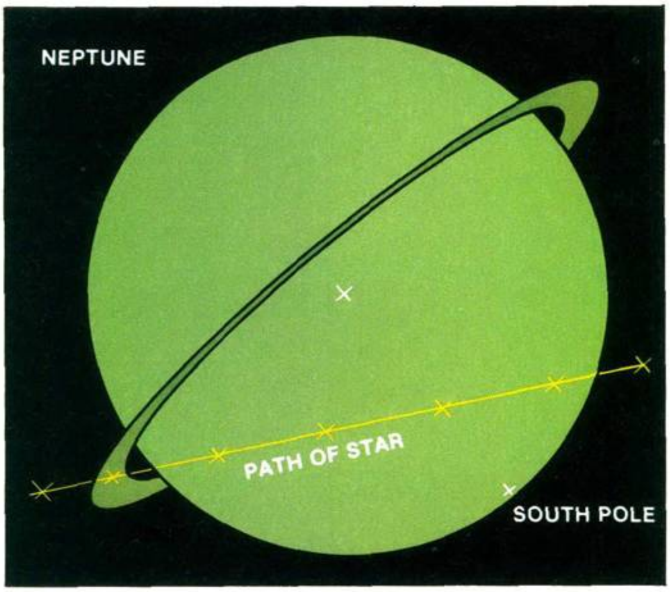
Neptune's Ring

The data in a stack of 14-year-old computer cards, lost since the measurements were made, indicate the presence of a ring around Neptune. The results, just now coming to light and made by Villanova University astronomer Edward Guinan, suggest that a 3,800 mile wide ring orbits cold Neptune.

This discovery was announced at a June meeting of the American Astronomical Society when Guinan outlined the story surrounding his prodigal data. In 1968, when Guinan was a graduate student at the University of Pennsylvania, he went to New Zealand to observe Neptune as it occulted a star. He hoped to learn more about the planet's atmosphere as he watched it dim the light of 7.8 magnitude BD -17° 4388 on April 7, 1968.

On his way home from making these observations, his plane made a stopover in the Soviet Union where Guinan's chart of measurements disappeared from his suitcase. The computer cards were still there but he felt their data was not detailed enough for his purposes. "It was to be my thesis," he said. "Instead I let it die. I never looked at it." Those cards were not studied for 13 years.



Studies show a ring may girdle Neptune.

When Guinan pulled out the cards last winter to give to one of his students to use for a project, they were warped from moisture and had to be repunched. When the information was finally displayed, Guinan and his students realized that the measurements indicated the light from the star had dropped inexplicably for 90 seconds when Neptune was well past the star. None of Neptune's known moons could account for the strange dimming either, so Guinan concluded that a ring of orbiting particles could have caused the drop in light.

If the ring exists, Guinan believes "it's small and closer to the planet than the rings of Saturn and Uranus." His calculations show the ring's inner edge is 2,700 miles above the cloudtops.

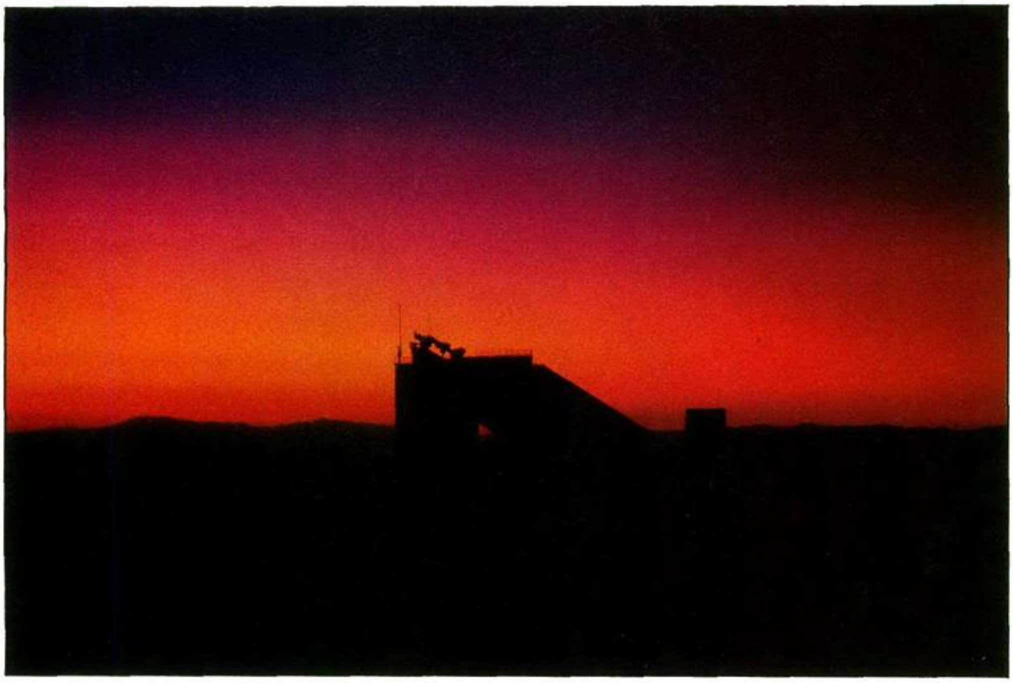
Guinan won't have a chance to repeat his observations until 1983 and so far he has not been able to find any other data that support or refute his 1968 observations.

Red at Night

Red sunsets over the past couple of months have been a delight for photographers, but a serious problem for the astronomers at Kitt Peak. Since the eruption of El Chichon on April 4, a monstrous cloud of sulfuric acid droplets in a globe-encircling mass of volcanic debris 12 miles high has spread from the Yucatan and dimmed light from celestial objects by as much as 40%, hindering the work of many astronomers. In the next six months the cloud will cover much of the northern hemisphere.

Ground-based scientists have bounced lasers off the cloud, and U-2 aircraft from NASA's Ames Research Center have flown through it collecting samples. In mid-May, Brian Toon of Ames

The volcanic ash cloud from El Chichon produced this spectacular red sunset at Kitt Peak. AURA photo. Below: Two weather service images of the cloud spreading across Mexico.



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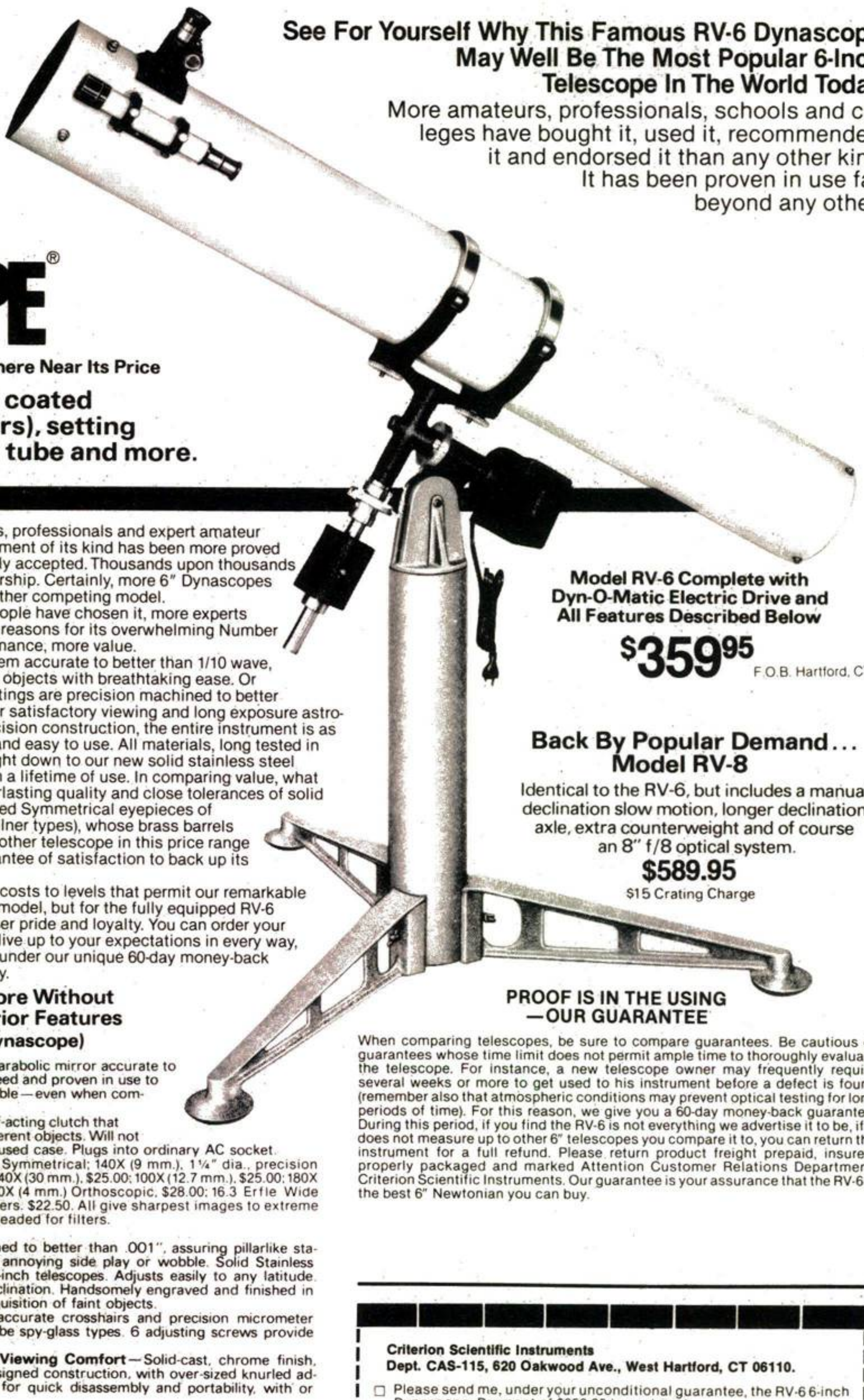

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reported that the cloud was as high as 19 miles over the tropical latitudes. "It will delight everyone with dramatic sunsets" as it drifts northward, he said.

Toon and others are concerned about the light-blocking effects of this cloud, which far surpass those of Mt. St. Helens. El Chichon's cloud of debris is denser than any in the northern hemisphere since the Alaskan volcano Katmai erupted in 1912.

The cloud may also result in lower temperatures as its obscuring effect increases, and a degree or more drop would not be unusual. Another potential danger from the debris is acid rain. Since the cloud is composed mainly of sulfur dioxide, it might combine with clouds in the lower atmosphere to produce a natural and highly acidic rain.

A Soviet Venus Mapper?

Since the Reagan Administration cancelled VOIR, rumors of a Soviet Venus mapper are stronger than ever. According to some sources, the mission might involve two spacecraft launched next March. The probes would map the surface from elliptical orbits at a resolution from several kilometers to 600 meters.

The craft would probably use synthetic aperture radars (SARs), the same type of equipment NASA gained experience with on the SEASAT mission and the second shuttle flight. Last year, NASA engineers devised a way for SARs to map an entire planet from an elliptical orbit. Before that, SAR could return data only from its point of closest approach to the planet. Since the Soviet craft will have elliptical orbits, American scientists think they will map the planet only at the latitudes that fall beneath their closest approach. But the craft may carry enough fuel to shift their orbits and image more of the surface.

The Soviet mapper would study just a portion of Venus' terrain at resolutions of one to a few kilometers. Earth-based radio telescopes have already mapped part of the planet at similar resolutions, but the Soviet mission would reveal 80% of the globe the radio telescope can't see. That data would significantly augment our knowledge of the planet.

NASA officials are trying to learn more about the Soviet plans. In the meantime, they continue to lay plans for their own Venus Mapper. "The Soviets put the first probe into Venus' atmosphere in 1967," says one American official. "If NASA had canceled plans for its Pioneer Venus probes because of a similar Soviet craft, we would have many unanswered questions about Venus' atmosphere. We shouldn't put aside our plans because the Soviets send a SAR to Venus first." *Van R. Kane.*

MY LUCKY STAR WENT NOVA
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Amateur Space Scope

The first phase of construction on the Amateur Space Telescope (see AstroNews, October 1980) began in August with the frame assembly that holds the electronic equipment and optical detectors.

The frame and onboard systems — including a prototype attitude control flywheel on magnetic bearings and an RCA 1802 based microprocessor — will fly on a Get-Away Special (GAS) cannister aboard a Space Shuttle flight in mid-1983. The main instrument, an 18-inch Ritchey-Chretien telescope, will be completed by mid-1984.

The AST will provide diffraction-limited photographic resolution from the UV to the near IR, and will detect stars down to 23rd magnitude. Two solid-state TV cameras for imaging, four photometers, and a UV spectrograph will also be onboard. The AST will transmit signals in digital form, so anyone with a few hundred dollars worth of equipment will be able to receive the signals and display pictures on a television screen.

During operations, a network of advanced amateur radio stations will control the AST through their own communications satellites. Locked in geosynchronous orbits, these satellites will allow almost continuous contact with the AST from a small number of stations and would allow any user to receive signals most of the day — even when the AST is below the horizon.

The Amateur Space Telescope will operate like an Earth-based observatory and will be available to students, amateur astronomers and professionals. Those with observational programs will submit proposals to the satellite controllers who will schedule the observations.

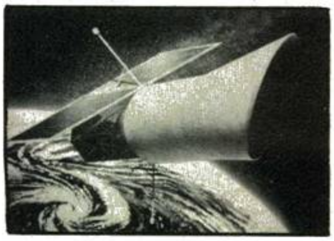
The Independent Space Research Group, Inc. (ISRG), a non-profit membership organization, coordinates the AST project and sponsors satellite design work by two teams of students and faculty at Rensselaer Polytechnic Institute and the University of Rochester.

Through volunteer labor and off-the-shelf equipment, the ISRG can develop its satellites for a fraction of costs normally associated with space hardware. Ham radio operators have used these techniques for more than 20 years to build amateur radio communications satellites for one percent of the cost to professionals. The total price of the AST will be less than $50,000.

Funds for the AST have come from dues and donations collected by the ISRG members. Memberships are available at annual fees of $10, Supporting, $25, Patron, $50, Sponsoring.

For more information contact ISRG at P.O. Box 1246, Troy, NY 12180, USA. *Jesse Eichenlaub.*

Artist's conception of the AST. ISRG photo



Rapid Pulsar

The discovery of an X-ray pulsar that blinks on and off seven times a second in the heart of a supernova remnant has given new support to the theory that massive explosions of stars leave behind compact cores of their original stellar bodies.

Astronomers Fred Seward and F.R. Hardnen Jr. of the Smithsonian Astrophysical Observatory found the rapidly pulsating object in the southern constellation Circinus while examining data obtained by the *Einstein* (HEAO-2) X-ray satellite.

The Circinus pulsar is only the fourth example of a collapsed object, such as a pulsar or neutron star, detected in a supernova remnant. The Crab

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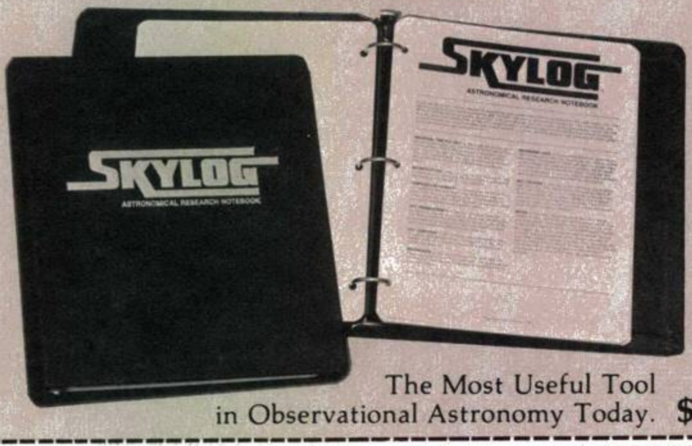
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ASTRO NEWS

and Vela Nebulae are the best known examples of remnants, but the absence of neutron stars in other supernova remnants has puzzled researchers.

Although the new Circinus pulsar supports the theory that core stars will probably be found in most remnants, it has produced its own intriguing puzzle.

The spin rate of the Circinus pulsar indicates a very rapid loss of rotational energy and a relatively young age of 2,000 years. By contrast, the calculated age of the pulsar's surrounding shell of stellar debris and gases is at least 10 times older — about 20,000 years.

It is difficult to explain the discrepancy between the ages of the supernova's core and its expanding shell, say Seward and Hardnen.

One possibility is that the supernova explosion was unusually energetic and that the shell is large for its age. Another more radical explanation concerns the existence of a second bright knot of X-ray emission in the remnant that indicates the pulsar and shell may originally have been separate parts of a binary star system. One star could have exploded first, producing the old shell we observe expanding outward in space. If the remaining binary companion continued on its own evolutionary course, it could have exploded later, with its core collapsing to create the X-ray pulsar seen by *Einstein*. The second bright spot could be the remains of the first star, although no X-ray pulses have yet been detected from it.

End of Eta Carinae?

A team of astronomers has reported that Eta Carinae, the most massive and luminous star known in the Milky Way, will end its life soon. They expect the end to come as an enormously violent explosion visible from Earth as a bright point of light even in broad daylight.

The exact time of the supernova cannot be predicted — it might happen tonight or 10,000 years from now. "Soon" has a different connotation on a cosmic time scale than it does on Earth.

Such a huge star — more than 100 times as massive as the Sun — has a relatively short lifetime of two million years, because it burns its hydrogen fuel at a tremendous rate. When the explosion occurs, it may emit more light than all the hundreds of billions of other stars in the galaxy.

Kris Davidson of the University of Minnesota and Nolan Walborn of Cerro Tololo Inter-American Observatory said the chemical composition of Eta Carinae tipped them off that it is nearing the end of its life.

Only one star in 10 billion is as massive as Eta Carinae. And if it were located in the northern hemisphere of the sky where more astronomers could readily see it, it would be far more famous. The region around Eta Carinae is one of the most intriguing in our galaxy.

Eta Carinae is usually just a normal star, but during the 1800s, it blew out some of its material and shined for a few years as the second brightest star in the sky. Gas from this explosion condensed into solid dust grains and the star became more difficult to see. Astronomers considered the large outflow of nebular material in the past as a second factor of the predicted explosion.

The third and key factor in the predicted explosion concerns one of the clouds of glowing hot gas that shot out from the star almost 200 years ago. Researchers found that this cloud contained more nitrogen than was expected, along with a dearth of carbon and oxygen. This situation could have been a result of nuclear reactions at the center of the star.

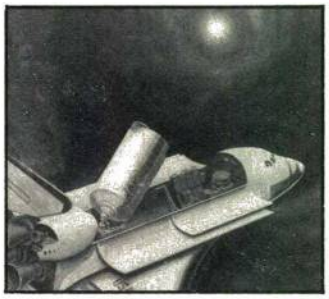
"If a star has had time to make nitrogen and shoot it out, we know that it already has lived through much of its life," says Davidson.

Solar Optical Telescope

NASA is negotiating the final contract for a Solar Optical Telescope (SOT) that will make measurements over the visible and much of the ultraviolet wavelength range of the Sun using a Gregorian optical system with extremely fine resolution. The observatory will be a major step forward in the study of solar physics since it will exceed the resolution limit imposed by Earth's atmosphere.

The telescope will study the origin and evolution of the Sun's magnetic field, as well as mechanical heating and mass transportation in the solar photosphere and chromosphere just above the Sun's surface, and in the transition area between the chromosphere and the Sun's corona, where the temperature climbs to 2 million degrees. In addition, SOT will study the Sun's internal heat transport mechanism.

The telescope is scheduled to fly on a space shuttle Spacelab in the late 1980s. Scientists on board the shuttle or at Johnson Space Center will control the scope, which will make several flights on Spacelab. NASA is studying how to deploy it on a space platform in the 1990s and plans for a 14-day mission each year for ten years at an altitude of 250 miles.



Artist's conception of the Solar Optical Telescope. NASA

The study of the Sun is unique in astrophysics because of its immediate impact on the human environment. Our radio communications, our safety in high altitude and space flight, our long-term climate changes, and possibly even the survival of our species all may hinge upon deep-rooted and complex fluid flow patterns inside our Sun. We can only study these processes through their indirect and delayed effects on the Sun's surface.

Recent developments in both theoretical and observational study of the Sun have focused increasingly on the smallest observable features. To understand solar mechanisms, scientists simultaneously measure many spectral bands at 0.1 arc second or better resolution.

To study solar features on the scale that many basic processes occur, investigators must combine high spectral resolution with a time resolution fine enough to observe changes in short-lived phenomena. To accomplish this, an observatory must be above the atmosphere complete with a large diffraction-limited telescope that astronomers can point toward the Sun while holding it stable to better than 0.1 arc second. NASA hopes the SOT will fulfill these needs.

NASA and Art

A space-age image enhancement technique used in the computer processing of photographs from NASA's unmanned spacecraft is allowing art conservators to better evaluate earlier compositions found underneath master paintings. This joint effort of JPL scientists and Los Angeles County Museum of Art curators has resulted in the successful use of image enhancement techniques to separate X-ray images of paintings where two or more works exist on the same surface.

William R. Leisher, head of conservation at Los Angeles County Museum of Art, asked JPL investigators to separate and enhance a painting found beneath the 17th century oil painting, *The Crucifixion*, by an unidentified Flemish painter.

Astronomer Dave Glackin and scientist Don Lynn, both image processing specialists, and computer analyst Raim Quiros, in collaboration with Jim Druzik and Pieter Meyers of the museum, developed the computer programs for subtracting the top painting from the bottom so that they can see the hidden painting in detail.

The Crucifixion, painted on paper, shows Jesus Christ being lowered from the cross by a group of followers. The underlying work, painted directly on the 16" x 24" wooden panel under the paper, shows a scene of a man and a woman seated at a table. The two are dressed in 17th century clothing, and the room is lit by sun shining through a window.

Art conservators commonly use X-ray photography to

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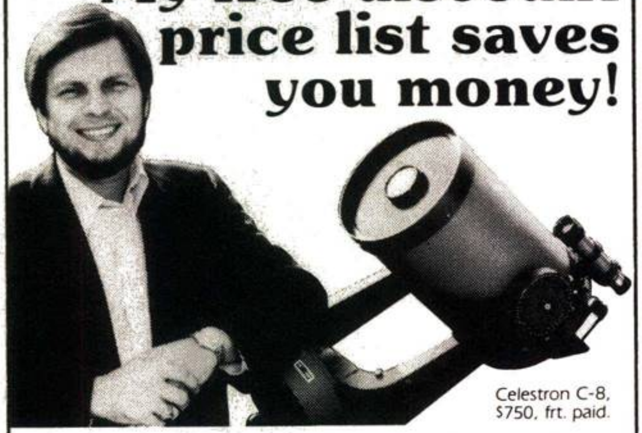

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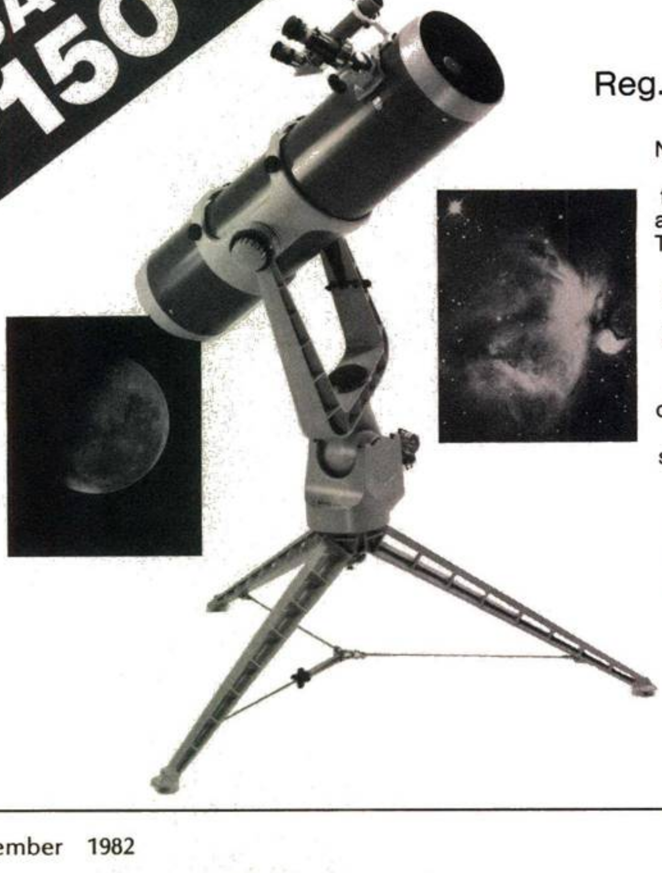

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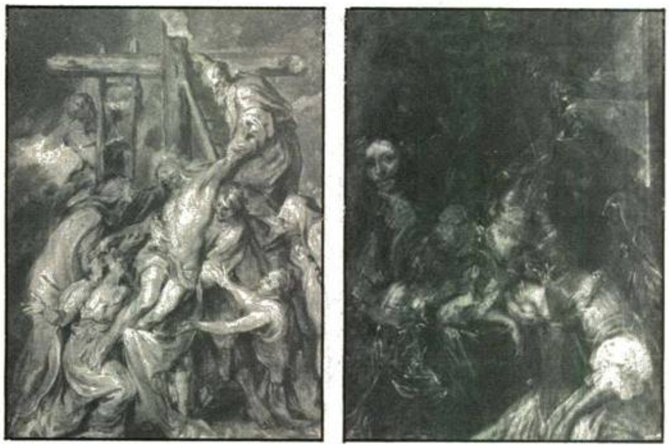
ASTRO NEWS

examine paintings. The X-ray photos often show that paintings or sketches exist beneath a top painting, but the works are not automatically delineated and appear as a blurred, double image.

"What we sometimes find is a completely different composition underneath," said Druzik, associate conservator at the museum. When that happens, he said, "there will always be a question in the curator's mind as to whether or not an unknown masterpiece exists under the top layer."

X-ray image of the painting hidden beneath "The Crucifixion." JPL is using its technology to aid art curators. JPL photo



In order to separate the two images, the JPL team first designed computer programs to minimize the appearance of the grain pattern of the wood on which the original work was painted.

Next, a photograph of the top painting was matched with the X-ray image. Brushstrokes from the X-ray version that matched the top painting were subtracted. Consequent subtractions removed most traces of the top painting, while the remaining bottom painting was computer-enhanced to bring out detail.

The pioneering development of the painting subtraction technique could lead to future systems designed uniquely for discerning and separating multiple X-ray images of paintings with designs under the surface. Such systems, said Druzik, "will be another invaluable tool for conservators and curators."

"This project is a good example of the applications of space technology to other problems of great public interest," said Davd Glackin of JPL. Glackin and Kurt Liewer, another JPL scientist, and the museum staff are undertaking a new task, using a high-resolution spacecraft photography system and JPL's image-processing facility to study the condition of the museum's *Codex Hammer*, a treatise on the nature of water by Leonardo da Vinci.

Future applications of computer processing to art conservation might include techniques to date paintings by determining the age of wood on which compositions were painted. Dendrochronology, the science of dating wood based on the number and character of tree rings, usually requires shaving wood away from the edge of the original wood panel. Computer enhancement of the grain would eliminate the need to remove original support material in order to date it.

ASTRO CALENDAR

August 11-13.	**IAPPP Springfield Meeting 1982.** Hartness House; Springfield, Vermont. Contact: R.C. Wolpert, 144 Neptune Ave., N. Babylon, NY 11704.
August 13-15.	**Stellafane.** Springfield, Vermont. Contact: Dennis di Cicco, 60 Victoria Road, Sudbury, MA 01776.
August 17-26.	**XVIII General Assembly of the International Astronomical Union** (professional meeting). University of Patras, Greece. Contact: Organizing Committee, General Assembly IAU, University of Patras, Patras, Greece.
August 27-29.	**Western Amateur Astronomers (WAA) 1982 Convention,** "Focus on Astronomy." Contact: Ames Research Center, Moffett Field, CA 94035.
Sept. 24-26.	**AstroFest.** Chicago Astronomical Society telescope fair and conference. Kankakee, Illinois. Contact: AstroFest, P.O. Box 596, Tinley Park, IL 60477.
October 4-6.	**Technology for Space Astrophysics, the Next 30 Years.** Co-sponsored by AIAA, SPIE, OSA. Danbury Hilton Conference Center and Inn, Danbury, Connecticut. Contact: Norman Geril, Perkin-Elmer Corporation, 100 Wooster Heights Road, MS 879, Danbury, CT 06810.
October 9-12.	**Conference on Lunar and Planetary Volatiles** (professional meeting). Lunar and Planetary Institute, Houston, Texas. Contact: Lunar and Planetary Institute, 3303 NASA Road 1, Houston, TX 77058.
October 13-16.	**18th Conference of the Great Lakes Planetarium Association.** Lakeview Planetarium, Peoria, Illinois and I.S.U. Planetarium, Normal, Illinois. Contact: Carl J. Wenning, Department of Physics, Illinois State University, Normal, IL 61761.
October 22-24.	**Custer Institute's Astronomy Jamboree.** Contact: Tom Carey (516) 271-2032 or George Lomaga (516) 298-4857. Astronomy Jamboree, Box 1204 Main Bayview Rd., Southold, NY 11971.
November 12-14.	**Space '82 — British Interplanetary Society.** Piccadilly Hotel, London. Contact: Executive Secretary, British Interplanetary Society, 27-29 South Lambeth Road, London SW8 1SZ.
November 15-18.	**Chondrules and their Origins** (professional meeting). Lunar and Planetary Institute, Houston, Texas. Contact: Pamela Jones, Lunar and Planetary Institute, 3303 NASA Road 1, Houston, Texas 77058 or Albert King, Department of Geosciences, University of Houston, Houston, TX 77004.

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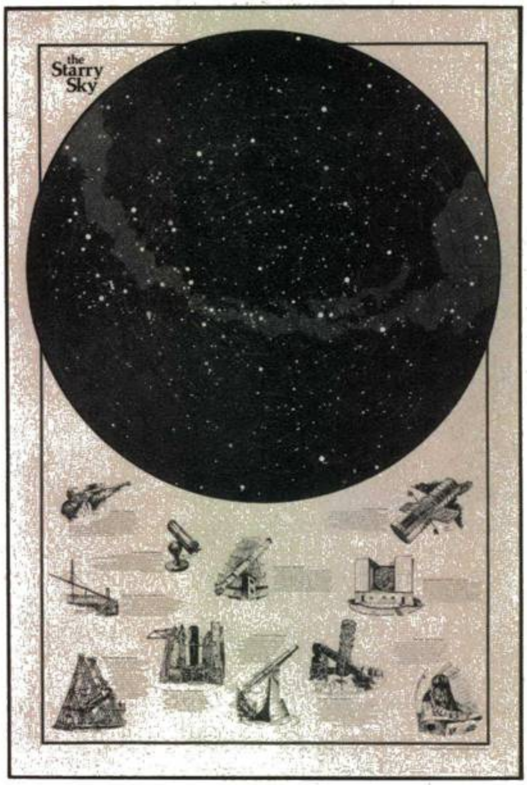

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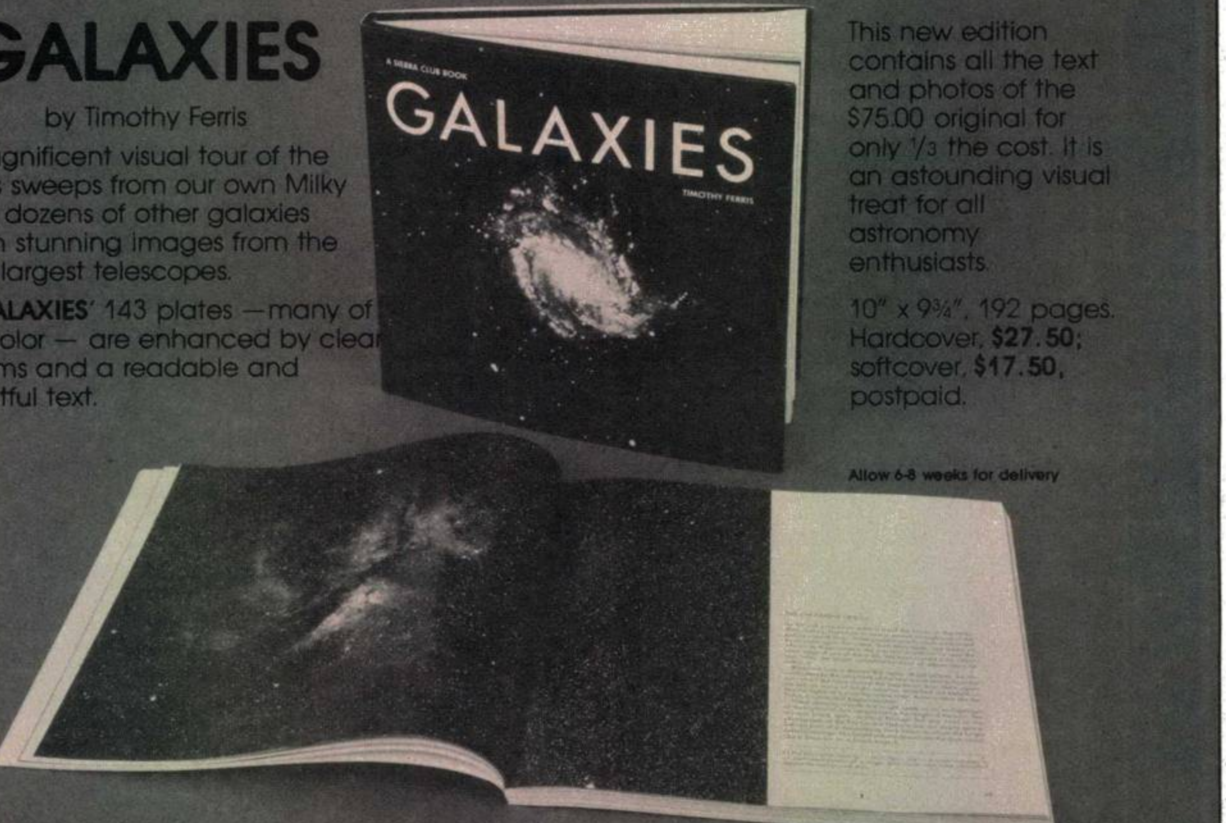

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ASTRONOMY REVIEWS

Photoelectric Photometry of Variable Stars: A Practical Guide for the Smaller Observatory
D.S. Hall and R.M. Genet
282 pages, softcover, $18.95.
International Amateur-Professional Photoelectric Photometry (1982)
[Publisher's address: Fairborn Observatory, 1247 Folk Road, Fairborn, OH 45324.]

This book is for small observatory astronomers, both amateur and professional, who want to do real astronomy, make real measurements, and publish real research in professional journals. All this is possible because photoelectric photometry — the electronic measurement of the brightness and color of stars — is at heart a simple process, and the necessary equipment has become relatively cheap and dependable. This book has everything you need to know to get started.

To do photometry with your telescope, you'll need three things: the equipment, the expertise to use it, and a list of stars to observe. All of these are covered in the book, beginning with a discussion of the best kinds of telescopes and equipment for photometry. It's encouraging to know that almost any kind of telescope will do.

The small observatories described range from 24-inch professional quality telescopes mounted inside domes down to a 6-inch stored in the corner of a garage. Lack of a fancy telescope is no excuse for missing the fun of photometry.

In addition to a telescope, you will need a photometer. This contains a photometric head, associated electronics, and a recorder. The sensor head attaches to the eyepiece end of your telescope and allows you to focus light from a single star on a light-sensitive device, usually a photomultiplier tube but occasionally a photodiode.

The electronics consist of a power-supply to run the photomultiplier tube and an amplifier to boost its weak signal. You will also need an instrument to record the data. This can range from a pencil and paper — with you copying each reading off the amplifier's meter or counter — up to a chart recorder, printer, or even microcomputer.

These three components of a photometer are described in detail in the book, including the basic theory of how they operate and practical designs for building your own devices. If you prefer not to build, the book describes two commercially available photometric systems of the "buy 'em, unpack 'em, use 'em" variety. But beware: these commercial units are not cheap. One manufacturer quotes a price of $1500 and another asks about $800 for a working system. On the other hand, this is less than many enthusiasts spend on their telescopes and, considering the new horizons a photometer can open up, the setup might easily be considered a small investment.

In any case, whether you buy your photometer or build it, you will need to know how to use it. Chapters 12 and 13 ("Observing Techniques" and "Data Reduction") tell you how to make measurements of variable stars and correct your observations to get accurate light curves. You can make all of the calculations on a pocket calculator, though a microcomputer will certainly speed things along.

But having the equipment and knowing how to use it won't put your name on a journal article. For that, you need one more thing: an observing program that tells you which stars are worth observing and how to interpret your results. Here again, the authors give you what you need to know. They discuss various kinds of variable stars, why you might want to observe them, and why certain kinds of observations are more important than others.

In Chapter 16, they suggest several research programs. They also recommend that you join a group called International Amateur-Professional Photoelectric Photometry (IAPPP), an organization of over 300 amateur and professional astronomers who work together on observing projects. Many of the amateurs in the group have published joint papers with the professionals.

In fact, small observatory astronomers, amateur and professional, have one great advantage over astronomers at big observatories when it comes to certain research projects: their time is largely their own. The long period variables, the RS Canum Venaticorum stars, the RV Tauri stars, and others have such long periods and such peculiar variations that they cannot be studied effectively from large observatories. Why? There, astronomers get observing runs that last only a few nights; continuity, essential for good results with these stars, is totally lacking. On the other hand, small observatory astronomers, facing little or no competition for telescope time, can observe every clear night. These monitoring programs are especially fruitful for cooperative efforts among groups.

Photoelectric Photometry of Variable Stars contains all of the basics, but it also contains some impressive extras. Chapter 6 helps you automate your telescope and photometer with a microcomputer, and Chapter 7 gives ideas on dual-channel photometers. Once you start tracing out light curves for variable stars, you will want to read Chapter 14, "Achieving Maximum Accuracy."

The 6-page bibliography will guide you to important references, and the two pages of addresses included will help you to communicate with important sources of equipment and data. And whether you are an amateur or a professional, you will enjoy reading Chapter 2, "A Search for Our Roots," a history of photoelectric photometry.

What's wrong with this book? First, it doesn't have an index — but the authors have divided the text into carefully organized sections which are listed in the table of contents. Second, the book contains many diagrams and black-and-white photos, and the printing process didn't always reproduce the photos with great clarity. But most users of this book will not be concerned with how pretty the pictures look.

What else is wrong with it? It's dangerous. It will tempt you. Once you read this book, you might start to think of your telescope as a tool. You may find that just looking at things or trying to photograph them isn't nearly as exciting as measuring the brightness of some variable star and watching it fade as it enters eclipse. *Photoelectric Photometry of Variable Stars* is real astronomy for real astronomers, both amateur and professional.

But be warned: photometry is not easy. If it were, everyone would be doing it and it wouldn't be such fun. Yet it's good to know that even a small observatory can make real contributions to astronomy, and this is the book that tells how to do it. *Michael Seeds.*

Astronomy: The Evolving Universe
(third edition)
Michael Zeilik
623 pages, hardcover, no price given
Harper & Row (1982)

Taking what others have called the "classic" approach, Zeilik begins with the sky as it appears to the naked eye and then reviews how astronomy evolved. Recounting the gradual increase of sophistication in astronomical techniques, he eventually works up to modern astrophysics and today's view of the universe.

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Space Travellers
Fred Hoyle and
Chandra Wickramasinghe
197 pages, hardcover, $17.50
Enslow Publishers (1982)

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Crown Optics	47, 48-49
Damart	71
Dey Optics	72
Dixon Spacescape	81
E&W Optical	83
Edmund Scientific	67
Gall Publications	83
Haag, Robt. A	82
Hansen Planetarium	73
Lumicon	31
Macmillan	25
Meade Instruments	2-3
Merrill Scientific	73
Optron	82
Santini Optical	29
Sciencefaction	65
Sinclair Research	60-61
Sky Instruments	29
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Star Tracker	80
TeleVue	69
Texas Nautical	83
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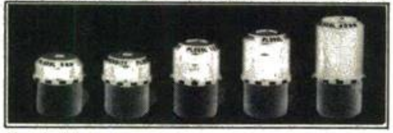

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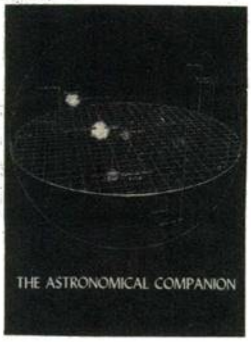
by Guy Ottewell



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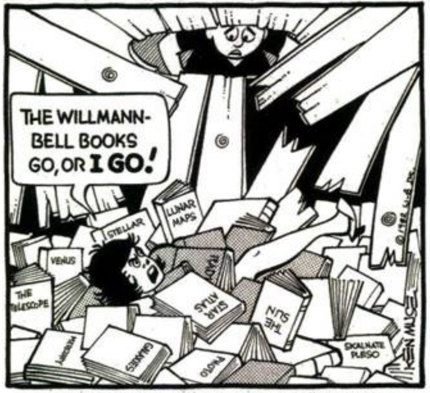

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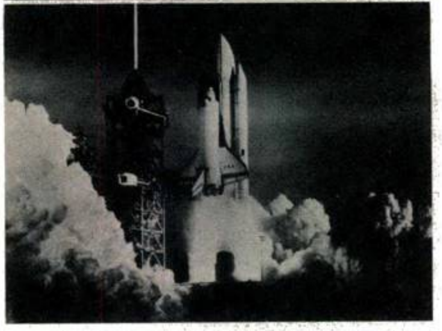

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What HEATS the Solar Corona?

by
Leon Golub

The Sun's corona, surely one of the most spectacular sights for those lucky enough to observe a total eclipse, went practically unnoticed throughout much of history. You can find ambiguous references to it which go back at least as far as Plutarch, but no one seriously studied the phenomenon until 1842. In July of that year, a total eclipse darkened a swath across central and southern Europe, and modern physical studies of the corona began. Within a few years, photography and the spectroscope became key tools for recording details of the corona and led to the first great puzzle in coronal research.

A look at the Sun during an eclipse shows that the solar corona extends many thousands of miles above the Sun's surface. When the light received from the corona is analyzed in a spectrograph, it appears to have about the same temperature as the solar surface — 6000 K. Nor is this any surprise: we expect such a temperature for a tenuous gas located just above the solar surface and heated by the powerful flow of radiation emanating from it. Yet this apparently unambiguous measurement presented observers with an enormous theoretical difficulty, because in the Sun's gravitational field a 6000 K gas should only extend up a few dozen miles, not the thousands of miles so clearly seen. This height, the so-called barometric scale height of a gas, is determined by its temperature, by the mass of the component atoms making up the gas, and by the strength of the local gravitational field. Although 6000 K is certainly hot by earthly standards, it isn't nearly hot enough to support the extended outer atmosphere we see on the Sun. The corona was physically impossible!

The resolution of this paradox came, as so often happens, as a complete surprise — and grew out of a totally unrelated area of research. To understand it, let's take a look at the evidence. The spectrum of coronal light is mainly a continuum, a rainbow of all colors, but it also contains a large number of bright, monochromatic emission lines. These lines usually indicate the presence of atoms which have had some of their outer electrons stripped away by collisions with neighboring atoms — a process called *ionization*. Emission lines result when some of these electrons recombine with the ionized atoms and give off a tiny blip of light at a specific wavelength. The signature of such emission is unique, and analyzing sets of emission lines — and absorption lines formed by a reverse process — provides a powerful means of identifying the components of hot gaseous mixtures in stars.

The identification process is normally foolproof, in the sense that given enough time and data astrophysicists can usually identify all the elements present. Scientists did not suffer for lack of data in the case of the corona, but by the mid-1930s, they noticed that none of the coronal lines were identifiable. In desperation, some researchers postulated a new element, coronium, to explain the observed emission spectrum, but when further work made it clear that there was no place in the periodic table for such an element, the coronium theory was abandoned.

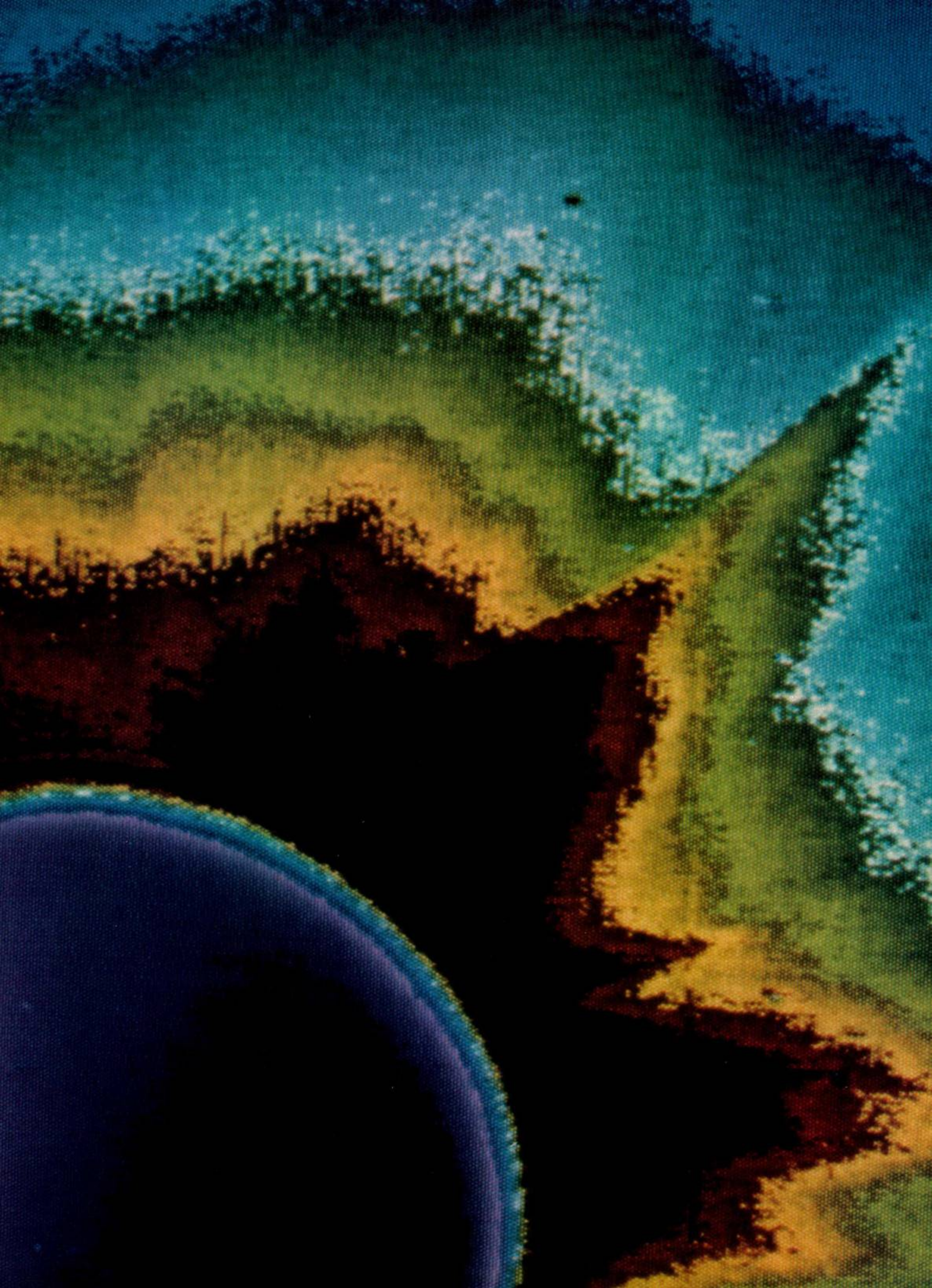
Earlier research done in 1931 provided an essential clue to the problem. French astronomer Bernard Lyot had used his newly-constructed coronagraph to "sample" the corona's light at times other than just during an eclipse. Lyot observed that emission lines from the corona were very broad — usually an indication that the emitting atoms are all moving at different speeds. The motion of each atom causes its bit of emission to be shifted in wavelength by the Doppler effect. The result of many atoms rushing around while they emit light is that each emission line has a certain width, and the hotter the gas, the wider the line. When the Doppler-width in Lyot's observations was analyzed, it showed that the coronal emission was coming from a gas that was hotter than a million degrees.

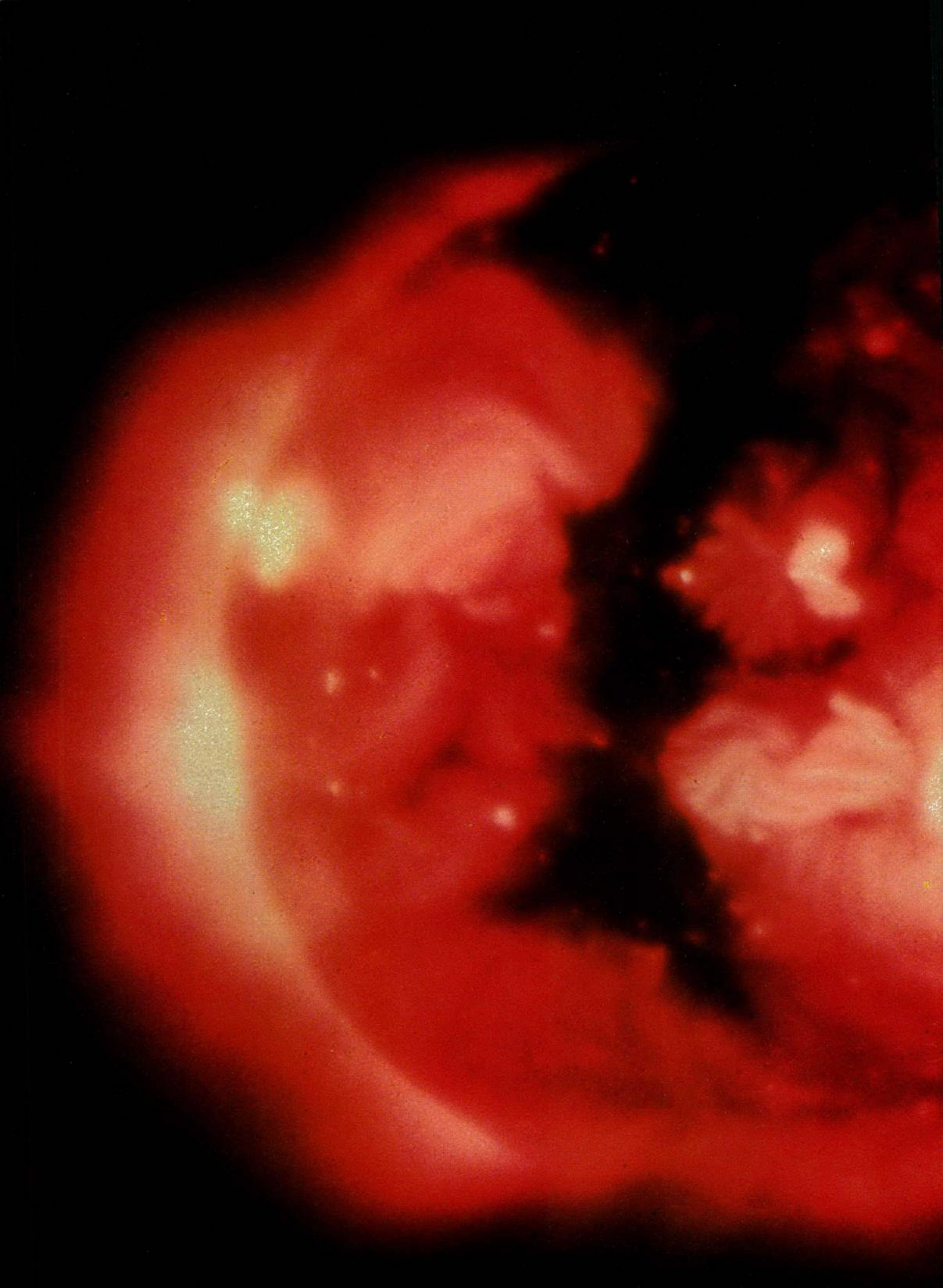
Unfortunately, Lyot and his contemporaries were not ready to believe this. It took another 10 years of work before astrophysicists accepted the identification of some of the coronal lines — which turned out to be atomic transitions of multiply-ionized iron plus those of many other common heavy, elements. The research that identified such high temperature emission features was done in laboratories and had nothing to do with solving the coronal problem. However, once the data were published and made available, astrophysicists realized that the coronal emission came from atoms with many of their outer electrons stripped away. Such high ionization states, in which eight or nine of the outer electrons in an element have been removed, occur in gases with temperatures from 1 to 2 million K. There was no getting around the fact that the corona was extremely hot.

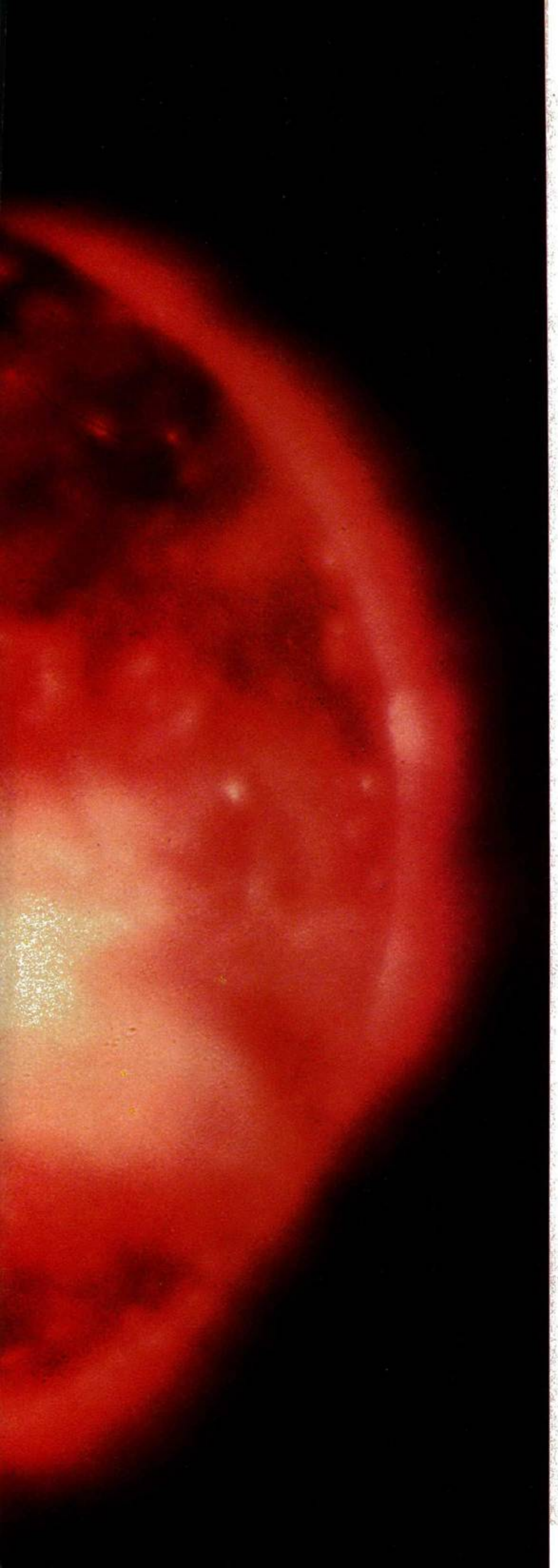
But what then of the much cooler 6000 K continuum? Where did it come from? It was plain, ordinary sunlight scattering off the coronal electrons and only appearing to originate in the corona. It didn't swamp the coronal emission — although the corona's line emission was inherently many thousands of times weaker — because the scattering process wasn't very efficient. Only a small amount of sunlight was reflected, so the two components wound up being comparable in strength.

More recently, astronomers using satellite observatories have found that the bulk of the radiation emanating from the coronal gas isn't even in the form of visible light: the corona is so hot that most of its output is in the form of soft X-rays. Fortunately for us, these X-rays are not usually very powerful and rarely succeed in penetrating Earth's atmosphere. Only during the strongest of solar flares does some of it "punch through."

This computer-processed image of the Sun's corona was taken by a spacecraft in Earth orbit. A coronal streamer extends to the upper right of the Sun's disk. NASA photo.







When seen at X-ray wavelengths, the Sun looks generally "dark" except where extremely hot, looping filaments of corona glow brightly. NASA photo.

Once astrophysicists satisfied themselves that the corona's temperature was extremely high, their research efforts switched to explaining what caused the great temperatures. By 1948, scientists proposed an idea which soon became the standard explanation: the corona is heated by sound waves, acoustic "noise" generated by turbulence at or just below the solar surface. The source of these very low frequency sound waves would be oscillatory motions of the Sun's surface, which would drive pressure waves in the overlying atmosphere in much the same way that the cone of a hi-fi speaker drives sound waves in air.

The most popular version of the model called for heating the corona by shock waves generated as the sound traveled up into the progressively rarified corona. In effect, it was heated by a succession of sonic booms. This mechanism got a significant boost in the early 1960s, when new observations showed strong vertical oscillations on the Sun, apparently just what the theory required.

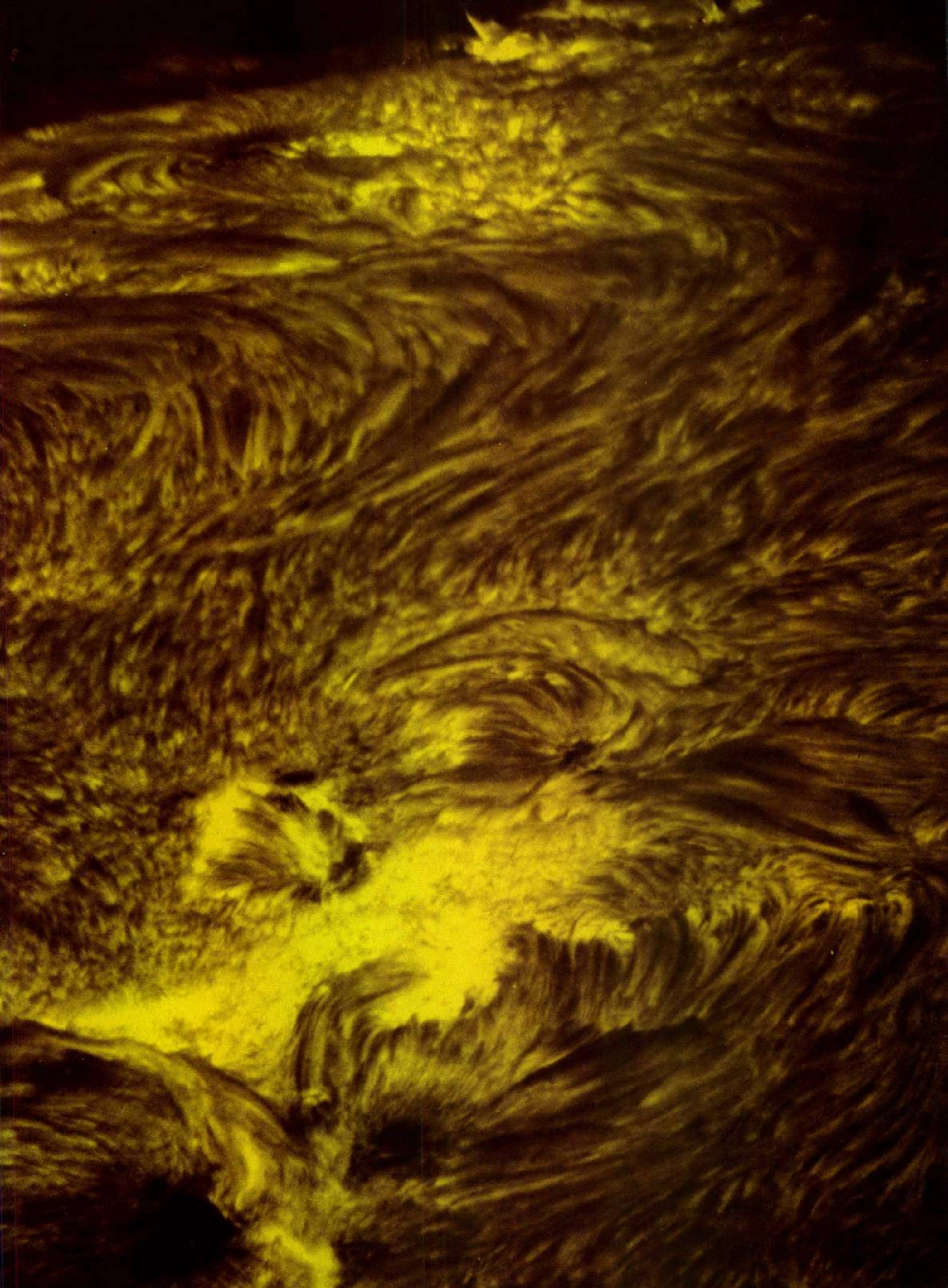
But the simple idea of coronal heating by acoustic waves has encountered numerous difficulties — not the least of which is that experiments designed to observe the sound waves propagating up into the corona haven't found them. There's no question these waves exist at the surface where the temperature is 6000 K, and we also see them at somewhat greater heights where the temperature begins to climb. But the wave energy seems to diminish before it reaches the corona and is probably not the cause of the heating.

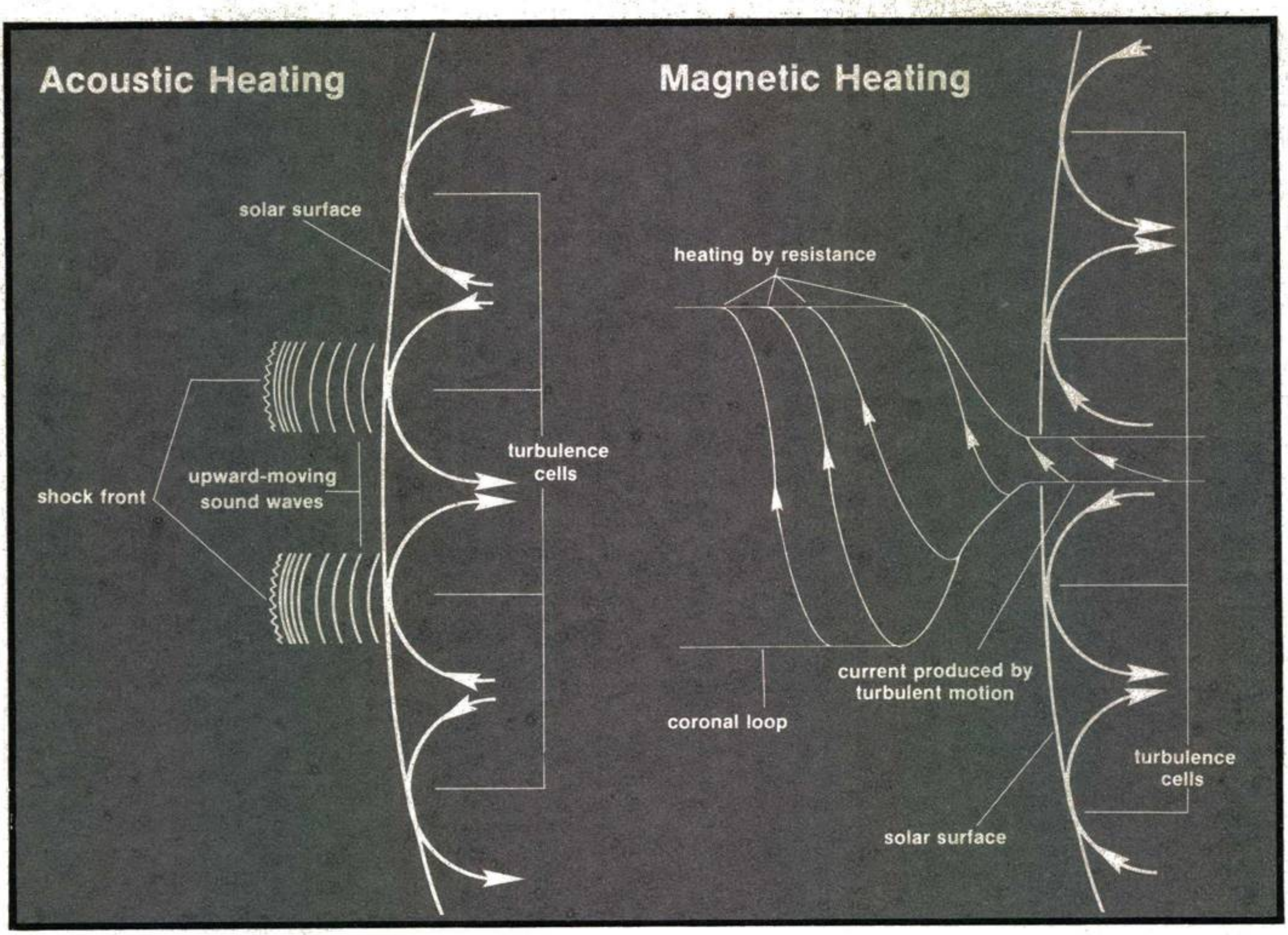
As is usually the case with an idea that many scientists like, the basic theory can still be "saved" — but only by calling on increasingly complicated and physically implausible explanations. So as the acoustic theory ran into difficulty, astrophysicists searched for a new explanation of the high coronal temperature, particularly at locations of strong magnetic fields. They now feel that the answer may lie in the very simple connection between magnetic fields and electric currents.

The interior of the Sun, for reasons still not well understood, acts as an enormous generator of electric currents which in turn produce powerful magnetic fields. In principle, the mechanism is a simple electric dynamo. When a conducting substance moves through a magnetic field, an electric current is generated in it. This current in turn produces an additional magnetic field. If the correct type of flow pattern is present, then the hot gas inside the Sun can act as a self-exciting dynamo. It will generate strong magnetic fields out of the many tiny "seed fields" which are initially present — fields produced inside the Sun which then bubble up to the surface.

Astronomers have known for many years that the corona is particularly bright and hot where the strongest magnetic fields have emerged. The sound-wave heating theory explained this by noting that the magnetic fields are closed — that is, the lines of magnetic force emerge at one point on the solar surface and reenter at some other point. The field then could act as a "trap" for acoustic waves, preventing their energy from escaping and thus heating up the locations where the magnetic field is strong.

The surface fields of the Sun are always changing due to the continual emergence of new fields bubbling up from inside and the turbulence of the solar surface. Any change in a magnetic field induces an electric field and these induced electric fields will cause electric currents to flow if they occur in a conducting medium such as the gas at the Sun's surface. Finally, whenever an electric current flows, some energy is lost due to resistance — and this lost energy heats the conducting medium. In its simplest form, the heating of the solar corona may be due to the same process





Left: A small region of the Sun's surface displays turbulent activity. Photo from Sacramento Peak Observatory. Above: Two models for coronal heating — acoustic and magnetic.

which causes an ordinary electric lightbulb to glow.

But when we examine the situation in more detail, it's not so simple, although the basic principle appears to be the same. In the case of the corona, it seems that the temperatures, magnetic field strengths, and rates of energy generation are so high that ordinary electrical currents are not produced and gas cannot remain in its ordinary form. Instead, the coronal conditions are such that any gas will become a plasma — a very highly conductive gas. This plasma fulfills much the same function as the copper windings in a dynamo, but the temperatures and densities are such that the classical relation between the applied electric field strength and the induced current no longer holds. Several complicated and only partially understood effects set in, including indications that the plasma may be heated by changes in pressure as well as by electrical resistance.

The problems of describing the behavior of the plasma in the solar corona are complex and highly interdependent. They strongly resist the simplified "back-of-the-envelope" approach that theorists use in attacking many physical problems. Study, theorizing, computer modeling, and experimentation must continue before astrophysicists feel confident that the new model is right.

This has created a rather curious situation: traditionally, astronomers have dealt with subjects far removed from terrestrial concerns. But their research into plasmas has begun to overlap with the work of engineers who are developing fusion power generating machines.

Much of the theoretical effort of understanding the corona's high temperature is being done with results of terrestrial fusion research and, in some cases, is carried out by the same people. Unlike most other areas of astronomy, solar research has produced a bonus that may have some immediate practical applications. And in a like fashion, the astronomers are in a position to benefit from years of detailed diagnostic work performed on terrestrial plasma problems.

The links between the two lines of work are even stronger than this. The same instruments built to look at X-rays coming from the corona can be used to record X-rays coming from fusion plasmas. Coronal telescopes can be redesigned to act as "microscopes" for viewing the complex events inside fusion devices. Also, many of the diagnostic calculations relating to the details of how hot plasmas radiate their energy can be used in both fields.

But the two lines of work also have differences. For instance, no one expects that the temperature and plasma density in the corona is high enough to produce fusion reactions, even though the confinement times naturally occurring on the Sun are many times longer than what we have yet achieved in the lab. Still, the strong ties between these two fields — which also include efforts to explain solar flares — are a major part of the present research effort in coronal physics. And although astronomers' initial intention in studying the Sun was not to aid fusion research specifically, it would be very gratifying indeed if our study of the corona could also be of use to the energy program.

Leon Golub is an astrophysicist at the Harvard - Smithsonian Center for Astrophysics in Cambridge, Massachusetts. He has studied solar X-rays with Skylab and stellar X-rays with the Einstein Observatory, an X-ray satellite. He is currently working on the development of a new type of X-ray telescope.

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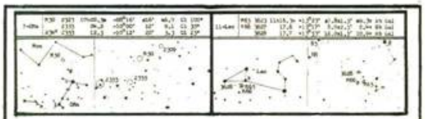

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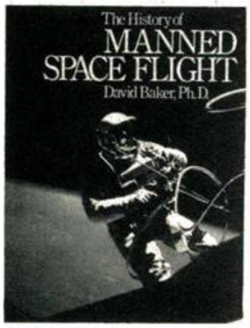

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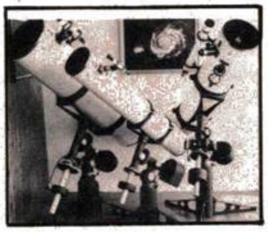

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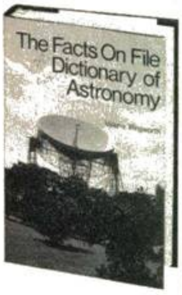

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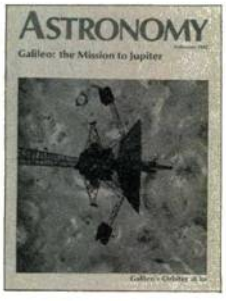

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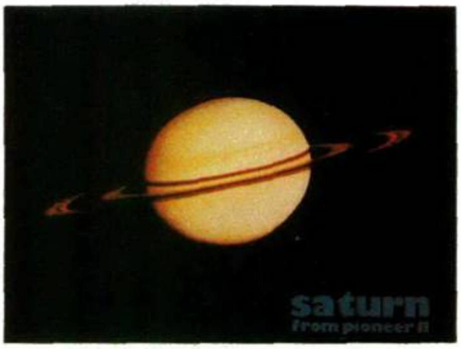
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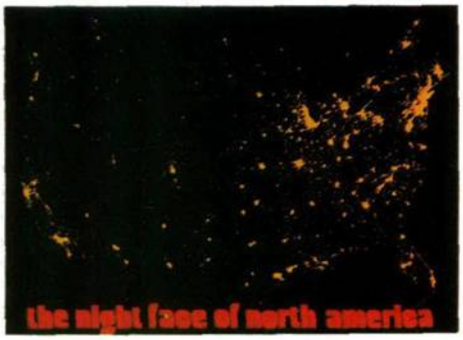
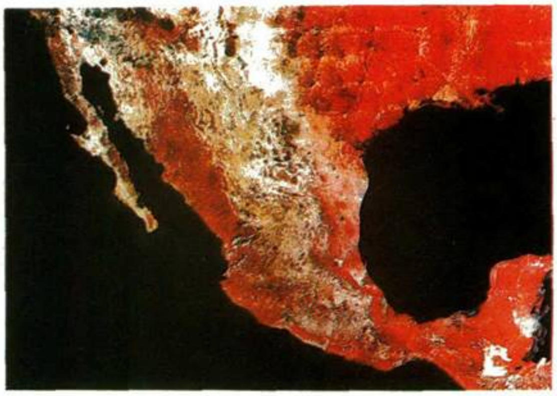
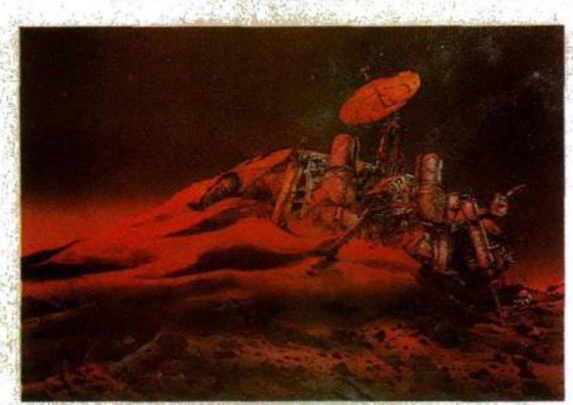

the night face of north america

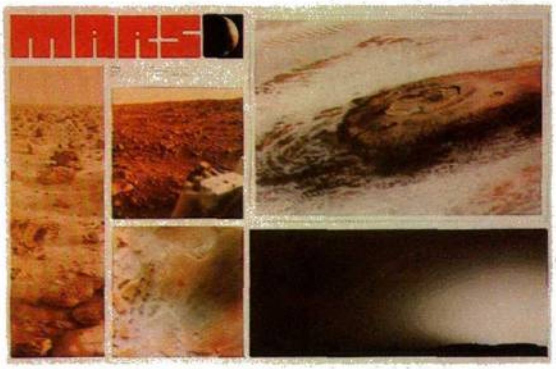
D. Night Face of North America: 17" x 22" $3.95
Our best seller pictures the lights of every city over 5,000 in the United States. Find your home town!



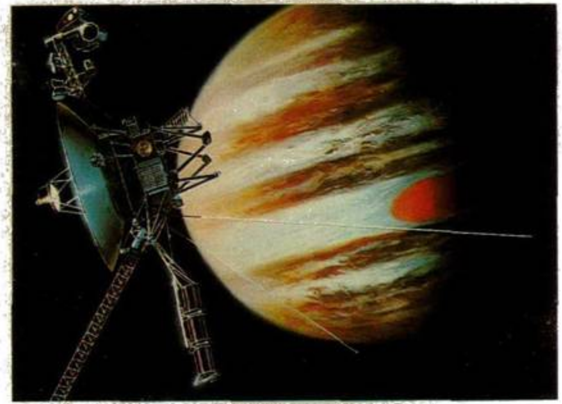
E. Mexico by LANDSAT: 22" x 34" $10.95
Magnificent, highly-detailed composite from satellite photographs, shown in bold color on heavy stock.

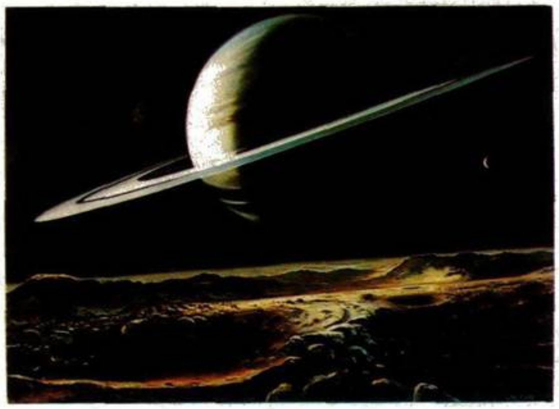


F. Viking at Mars: 24" x 36" $7.95
Artist Bruce Bond captures our pioneer spirit in this illustration of how Viking 1 might look thousands of years from now.



G. Mars: 22" x 34" $5.95
15 miles high and 400 miles wide, Olympus Mons dominates this dramatic poster.



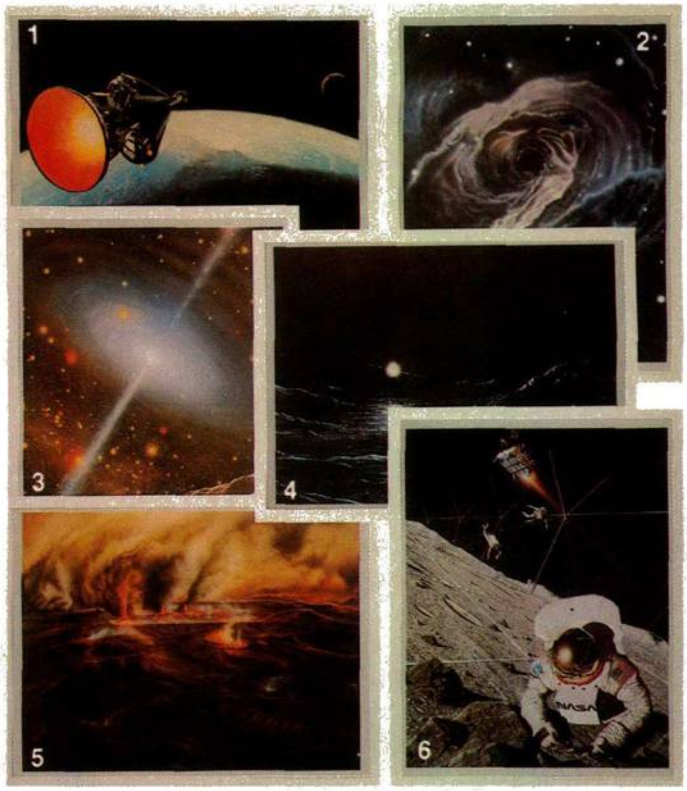


H. Jupiter & J. Saturn: 22" x 34" $12.00 each
Superior reproductions of John Clark's work commissioned by ASTRONOMY. Explorer examines the Red Spot of Jupiter in the first, while ringed Saturn looms above a rocky moon in the second. Order the set for $20.00 and save $4.00

K. Space Art Collection:
17" x 22"
$2.95 each, all 6 for $12.95

Each illustration was featured in an ASTRONOMY article. These very popular pieces are an inexpensive trip to deep space.

1. *Zeta Reticuli*
   by John Clark
2. *Black Hole*
   by Mark Paternostro
3. *Radio Black Hole*
   by Adolph Schaller
4. *The Sun from Pluto*
   by James Hervat
5. *Tharsis Erupting*
   by Mark Paternostro
6. *Asteroid Miners*
   by David Egge



the backyard astronomer

capricornus

The arrangement of the planets this month invokes a sense of their imminent departures: Mercury is nearly invisible, Venus and Saturn will be disappearing into the solar glare by month's end, and Jupiter follows next month. But there's still time to squeeze in some observations — and the planets look as lovely as ever.

Mercury

The present evening apparition of Mercury, begun last month, will be the year's poorest. The planet's elongation from the Sun is a wide 27°, but the line of elongation between Mercury and the Sun makes a shallow angle to the western horizon in middle-northern latitudes. The result is that Mercury sets just 51 minutes after the Sun does on the date of maximum elongation, September 6. Next month's morning apparition will be far better.

Venus

Easily visible in the morning sky before sunrise at the start of September, Venus will sink rapidly day by day until by the end of the month, it will almost vanish in the blaze of the Sun.

This means you shouldn't pass up any clear mornings: wrap up your observations early in the month, this will be your last chance to see the planet (other than in daylight) until it emerges from the Sun into the evening sky in mid-December.

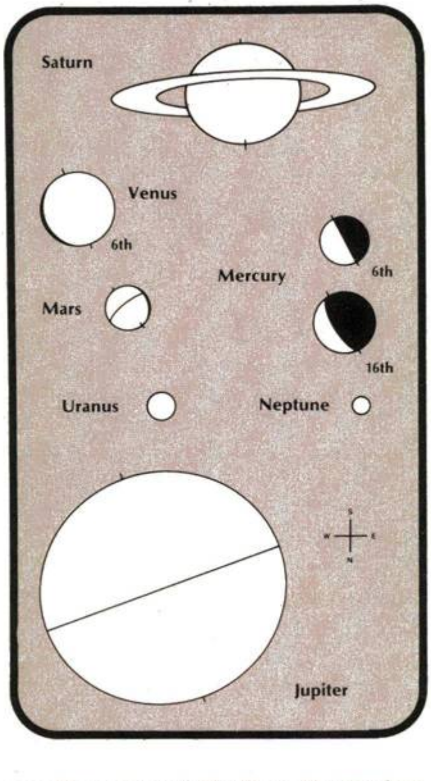
In the eyepiece, Venus will look small — about 10" of arc in diameter — and its phase will be nearly "full." The planet has moved most the way to the other side of the Sun from us and just about all of its visible disk is now illuminated.

The glowing swirl of M-8, the Lagoon Nebula, is the showpiece of the constellation Sagittarius. The photo, taken by David Healy, wins this month's "Best Astro-Photo" award. He used a 14-inch Schmidt-Cassegrain at about f/7 with a telecompressor, hypersensitized 2415 film, and a 24-minute exposure.

At 8:23 UT on the 6th, Venus will pass 44' of arc north of the first magnitude star Regulus, in Leo. Since this happens shortly before Venus rises for North America, you'll have to look in on the pair after the event, when Venus lies slightly to the east of the star.

Earth

The Sun crosses the celestial equator southbound at 8:46 UT on September 23, thus marking the equinox. Autumn begins for the northern hemisphere, spring in the southern.



Mars

Sweeping eastward through Libra and the northern extent of Scorpius, Mars moves closer toward its stellar namesake, Antares. In a telescope, the planet isn't very large: 6" of arc across on the 17th.

Mars' conjunction with Uranus at 12:41 UT on the 22nd will be relatively distant: 1° 27' separates them. In addition, the time of closest encounter happens when they are out of sight from North America. You'll have to settle for viewing them before or after the event, on the evenings of the 21st or the 22nd. A low-power eyepiece should place them both in the same field of view: orangy-bright Mars and dim grey-green Uranus.

At 5:39 UT on the 23rd, Mars passes within a degree (42') of the 2.3 magnitude star Delta (δ) Scorpii. At the time of closest approach, the pair have set for observers on the North American continent, but those in Hawaii will see the star and planet together in the southwestern sky.

Asteroids

1 Ceres (magnitude 8.5) lies in eastern Libra, near the border with Scorpius. At 20:50 UT on the 26th, it will pass 5' of arc north of Uranus. Unfortunately, closest approach comes during daylight for North America — you'll have to observe the two objects as soon as it gets dark enough to find them. Ceres' positions:

10th: 15h 36m 49s, -18° 31.5'
20th: 15h 49m 35s, -19° 36.2'

Ceres sets about 9:30 p.m. daylight time in the mid-September.

2 Pallas (9.8) is in southern Bootes. Its positions:

10th: 14h 29m 26s, +10° 52.0'
20th: 14h 43m 26s, +9° 36.5'

Pallas sets around 9:00 p.m. daylight time on September 15.

3 Juno (10.6) lies close to the border between Ophiuchus and Serpens Cauda. Its positions:

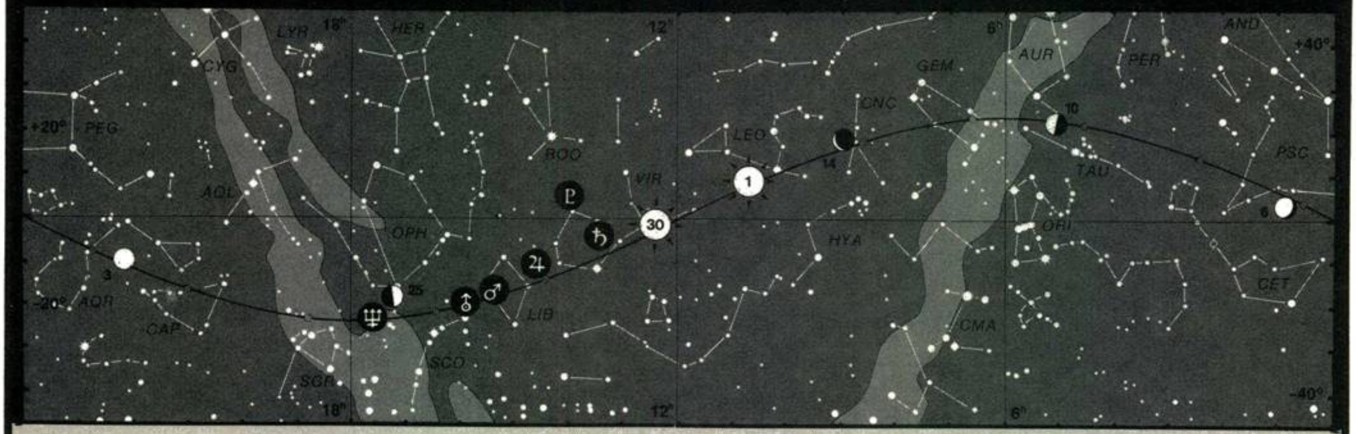
10th: 17h 43m 40s, -10° 09.3'
20th: 17h 49m 16s, -11° 00.9'

Juno sets a little after midnight daylight time on September 15.

4 Vesta (6.5) is moving southwestward in southern Capricornus. Its positions:

10th: 21h 06m 53s, -24° 53.1'
20th: 21h 04m 11s, -25° 01.1'

planetary data — september 1982


LYR
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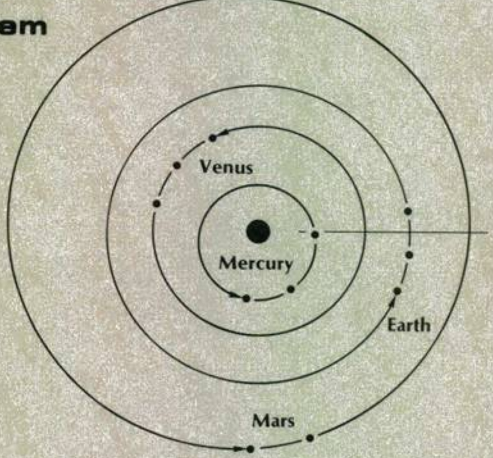
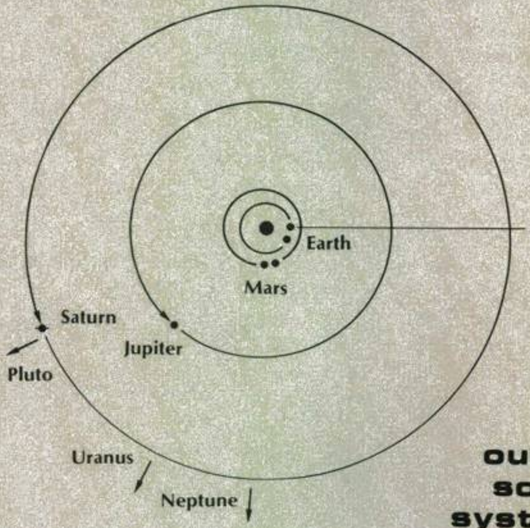
inner solar system


Venus
Mercury
Earth
Mars


Earth
Mars
Saturn
Jupiter
Pluto
Uranus
Neptune

outer solar system

		Date	Mag.	Angular Size	% Illum.	Distance (AU) from: Earth	Distance (AU) from: Sun	Longitude: Heliocentric	Longitude: Ecliptic	R.A. (1982.8)	Dec
Sun		1	−26.7	31.7′	—	1.01	—	—	158°14.8′	10h 39.5m	+8°50.5′
		15	−26.7	31.9′	—	1.01	—	—	171°50.2′	11h 30.0m	+3°14.5′
		30	−26.7	32.0′	—	1.00	—	—	186°30.9′	12h 23.9m	−2°35.0′
Mercury	☿	1	+0.3	6.4″	63%	1.02	0.47	259°48.5′	184°09.7′	12h 14.6m	−3°24.9′
		15	+0.7	8.2″	38%	0.81	0.44	300°24.3′	195°50.3′	12h 55.4m	−9°48.3′
		30	+2.6	10.2″	2%	0.65	0.36	357°52.4′	190°39.5′	12h 36.6m	−7°09.3′
Venus	♀	10	−3.4	10.2″	97%	1.65	0.72	132°14.4′	152°09.5′	10h 20.0m	+11°41.5′
		30	−3.4	10.0″	99%	1.69	0.72	164°44.3′	176°59.3′	11h 52.9m	+2°20.9′
Mars	♂	15	+1.0	6.0″	89%	1.55	1.45	275°40.0′	236°08.9′	15h 35.8m	−20°36.1′
Jupiter	♃	15	+1.3	32.5″	100%	6.05	5.41	226°18.3′	218°05.5′	14h 25.8m	−13°27.0′
Saturn	♄	15	+1.0	15.8″	100%	10.58	9.71	204°05.1′	200°43.4′	13h 21.7m	−6°08.4′
Uranus	⛢	15	+6.0	3.6″	100%	19.32	18.90	244°00.5′	240°50.1′	15h 56.2m	−20°15.7′
Neptune	♆	15	+7.8	2.4″	100%	30.21	30.27	266°12.4′	263°56.5′	17h 35.4m	−22°03.3′
Pluto	ꟼ	15	+13.8	—	100%	30.73	29.94	206°37.5′	205°06.5′	13h 58.8m	+5°35.9′

moon data

Full Moon	September 3 at 12:28
Last Quarter	September 10 at 17:19
New Moon	September 17 at 12:09
First Quarter	September 25 at 4:07
Full Moon	October 3 at 1:08
Last Quarter	October 9 at 23:26
Perigee: September 13 at 18h .	367,500 km
Apogee: September 25 at 19h .	404,100 km

universal time

Astronomers the world over use an unambiguous system of time reckoning — Universal Time (UT) — based on a 24 hour clock. Times given in The Backyard Astronomer are UT unless noted otherwise. To convert UT into your local daylight time, subtract the following number of hours for each time zone: EDT, 4; CDT, 5; MDT, 6; PDT, 7; Alaska, 9. For example, if an event is to happen at 03:00 hours UT on June 7, then EDT for the event is 11 p.m., June 6. Likewise, 03:00 UT on September 2 becomes, in PDT, 8 p.m., September 1.

On April 14, 1982, Andrew Steinbrecher gathered the widely separated planets Mars, Jupiter, and Saturn into one frame using a triple exposure. He did it with a 16-inch f/5.5 scope, a 3x Barlow, and Ektachrome 400 film. The exposures were ¼ second for Mars, ½ second for Jupiter, and 2 seconds for Saturn.

Vesta transits around 10:30 p.m. daylight time at mid-month.

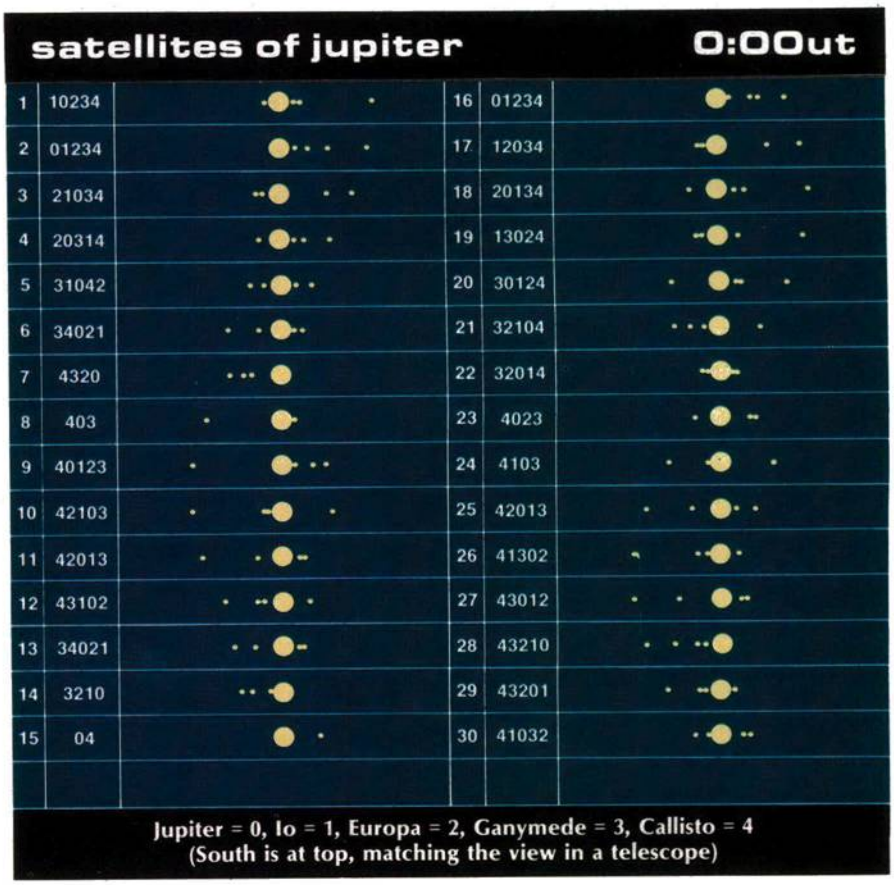
To facilitate plotting their positions in a star atlas, all asteroid coordinates are for the epoch 2000.

Jupiter

This giant gas planet is sinking lower in the west day by day; with an elevation of 17°, 45 minutes after sunset on the 1st, Jupiter will be 8° high by the 30th. This will be your last full month to see the planet; during October it will disappear from view and remain too close to the Sun to be seen until it emerges into the morning sky in late November.

Saturn

From an elevation of 11°, 45 minutes after sunset, Saturn will be less than a degree high on the 30th. As you watch it slide into the glow of twilight, think back on the splendors of the observing season just past — and look forward to the new one that begins when the planet reappears in the morning sky



satellites of jupiter **0:00ut**

1	10234
2	01234
3	21034
4	20314
5	31042
6	34021
7	4320
8	403
9	40123
10	42103
11	42013
12	43102
13	34021
14	3210
15	04
16	01234
17	12034
18	20134
19	13024
20	30124
21	32104
22	32014
23	4023
24	4103
25	42013
26	41302
27	43012
28	43210
29	43201
30	41032

Jupiter = 0, Io = 1, Europa = 2, Ganymede = 3, Callisto = 4
(South is at top, matching the view in a telescope)

in November.

Uranus

Uranus is easy to find, in Scorpius just a few degrees to the west of Beta (β) and Omega (ω) Scorpii. And in addition to these finder stars, the bright planet Mars will lie near Uranus on the nights of September 21 and 22. During the day, Mars will pass a degree and a half south of Uranus. A few days later, the planet has a very close conjunction with the asteroid Ceres (see the Asteroids section above).

Uranus has a 6th magnitude disk 3.6" of arc across — large enough to show clearly with medium-power eyepieces. It takes a large scope to make the disk display any color, but even that will only reveal it to be greenish-grey.

Neptune

Neptune ceases its westward motion on September 6 and begins direct (eastward) motion. The 7.8 magnitude planet lies a third of a degree south and $1\frac{2}{3}^\circ$ west of the 4.9 magnitude star 58 Ophiuchi. Neptune has a grey disk 2.4" of arc across.

close-up on capricornus

The fall constellations have a reputation for being dim and dull — and it's true that none have the splendors found in the groupings of the two neighboring seasons, summer and winter. But to write off the season is to miss out on a lot. And besides, a steady diet of breathtaking wonders would soon pall, so give your eye a rest and explore **Capricornus**, a constellation whose sights are simple but subtly attractive.

The constellation is one of the zodiacal twelve and in mythology it represented a sea-goat — a curious hybrid creature with the forequarters of a goat and the tail of a fish.

Yet like so many other constellations, it's hard now to make out the figure the ancients saw — the ordinary naked-eye view is of a broad triangle, rather shield-like. Despite the fact that only three of its stars are brighter than fourth magnitude, the group is surprisingly easy to locate — unless you're viewing from a large city. The reason for this is that the two endpoints of the "shield" are marked by bright stars and all the rest of the constellation falls in between.

Let's begin our sky-tour this month with the western-most end of the constellation. The bright tip of the shield here is, appropriately, the star Alpha (α). Alpha carries the name of Al Giedi, which is Arabic for "the goat." The star is a double, which you might ascertain with your naked eye, and will certainly become obvious as soon as you turn your scope on it.

With a telescope, keep your eyepiece powers low because the separation between the two components comes to more than 6' of arc. But although these two yellowy stars, roughly matched in spectral type and brightness (**Alpha^1** is 4.5 magnitude, **Alpha^2**, 3.6), look like a true double star system, they are only an "optical double" — a chance alignment of two physically unconnected stars.

Now take your telescope and examine Alpha^1 at higher power — you'll discover that it has a 9th magnitude companion 46" of arc to the southwest. Then turn your attention to the brighter star Alpha^2, where you'll find that it also isn't alone. At first, it looks as if it has only a dim 11th magnitude companion lying some 7" of arc to the southeast. But a close look with a 6-inch or larger scope on a night of good seeing will reveal that this companion is actually two stars separated by a little over a second of arc! Can you split them?

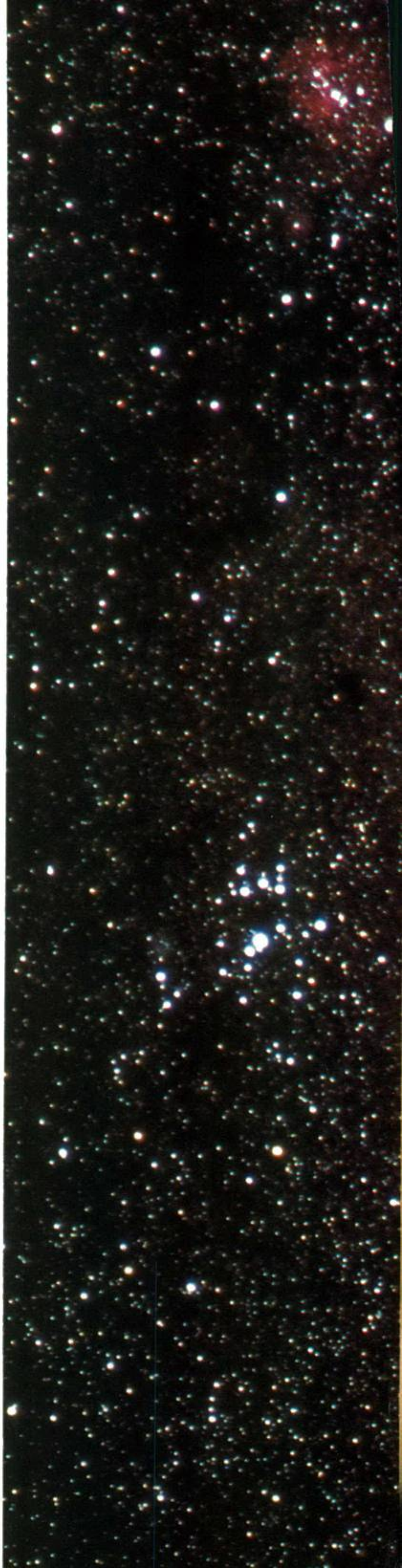
Our next sight lies only a short distance to the south and east of Alpha: it is another triple system, **Beta (β) Capricorni**, which has the popular name of Dabih. At least part of the Beta system falls an easy target to even modest optical power since the two brightest components Beta A and Beta B — 3.2 and 6.2 magnitude, respectively — are separated by 3½ minutes of arc; a line between them runs almost east/west.

Finding the third telescopic member calls for discerning a 10th magnitude star very close to Beta B; less than a second of arc separates them, and they are also aligned just about east/west.

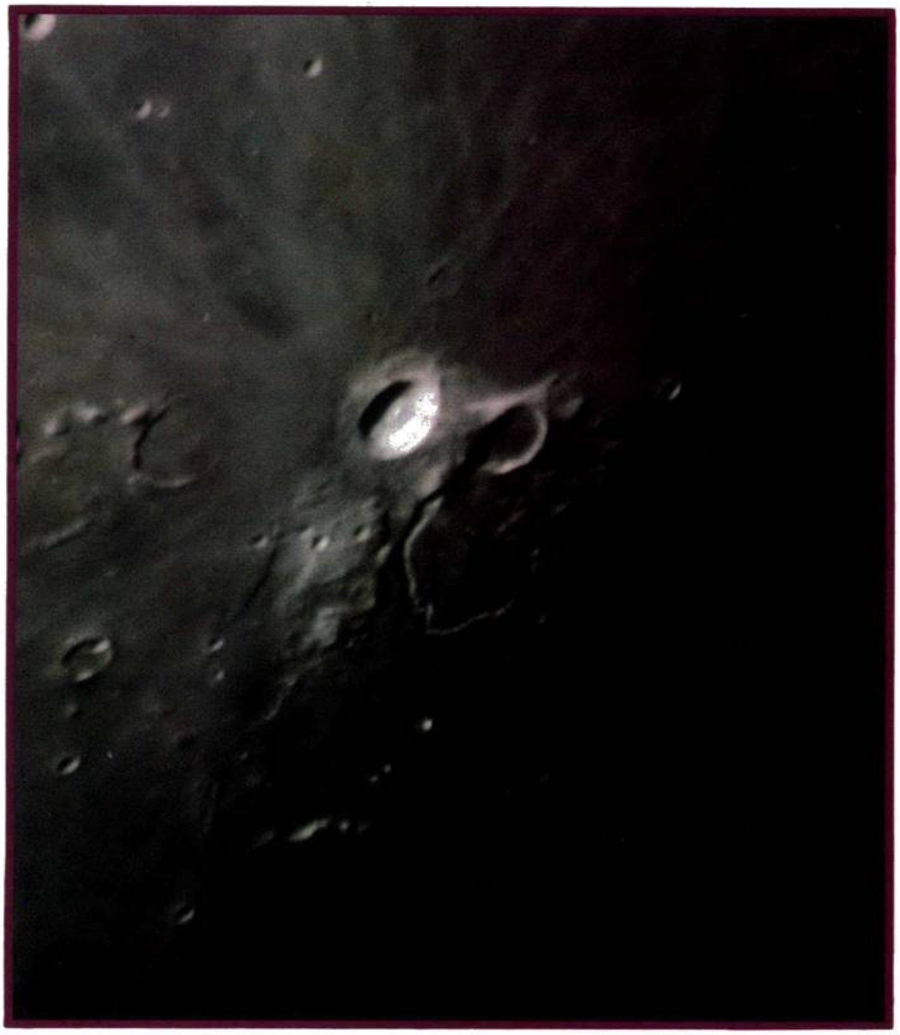
In reality, Beta A and B are what astronomers term a "common proper motion" pair. They appear to move in the same direction on the sky, but display no orbital motion around each other. They may or may not be a true physical pair — only time will tell.

In addition, the star Beta A is a spectroscopic triple; far too close to be seen by even powerful telescopes, two companions orbit this star. We know they are there only because the lines in Beta A's spectrum periodically split into multiple components — and each split spectral line betrays, through the Doppler shift, the presence of an unseen companion.

Let's now shift our attention to the eastern tip of Capricornus. There we find the brightest star in the constellation, **Delta (δ) Capricorni**,



Glowing bright red at the lower center of the picture is the star/nebula Eta (η) Carinae, a jewel of the southern Milky Way. Astronomers think this object may supernova in the next few thousand years. Ronald Royer took the picture with a 105mm lens at f/2.5 on Ektachrome 200 with a 60-minute exposure.



The bright crater Aristarchus is suspected of producing transient volcanic phenomena such as gas-venting; its darker companion to the west, Herodotus, appears inert. Curving below them is the sinuous rille Schroeter's Valley. Jean Dragesco used a 14-inch Schmidt-Cassegrain and Ektachrome 200.

also called Deneb Algiedi. It shines at magnitude 2.9 and lies about 50 light-years away. The star is an eclipsing binary: two stars whose orbital plane lies in our line of sight. Every 1.023 days, the dimmer of the two stars covers up the brighter and the combined magnitude of the pair drops slightly. Curiously, the drop in magnitude during eclipse is only 0.2 — difficult to notice. Can you spot the changes? From Delta, look just 4° northeast. Near the star **Mu** (μ) **Capricorni** lies the spot where Johann Galle first detected the planet Neptune on September 25, 1846 — thanks to orbital calculations made by Urbain Leverrier.

Let's now take a glance to the southeast of Beta Cap and examine two of Capricornus' other double stars. **Pi** (π) **Capricorni** is a pair of fifth and ninth magnitude suns separated by a sliver of sky only 3.2″ of arc wide; they are in position angle 148°. This pair is quite a test for a 4-inch, but if the night is clear and steady, you should be able to resolve this system with high powers.

The second is the double system of **Omicron** (o) **Capricorni**, which will look like a matched pair of pinpoints through your eyepiece. These stars, at magnitude 6.1 and 6.6, are separated by 22″ in position angle 239°. Try splitting them with low power. If you have a small reflector, this might be a nice pair to check your mirror alignment on — it will also help sharpen your eye to the subtleties of double star observing.

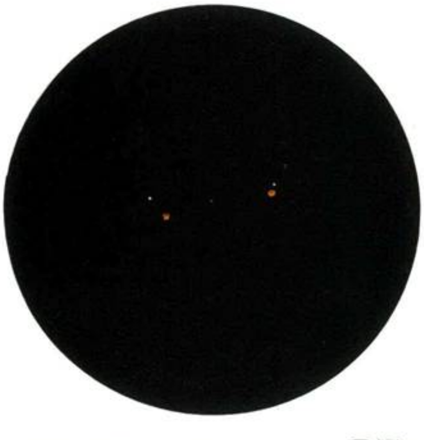
Capricornus also contains a long period Mira-type variable — **RR Capricorni**. On average, it swings between maximum and minimum light every 277 days and, like many long-period variables, its magnitude range is large — 9.5 to 14.5. On occasion, RR Cap has reached maxima as bright as 7.8, but in recent years its peak has been about two magnitudes lower. According to predictions by the AAVSO, it should be at maximum light late this month and in early October. How bright will it get this time?

For our last object, swing your scope around to **M-30** (NGC-7099), one of the lesser-known members of Charles Messier's list of selected non-cometary objects. A little low-power sweeping just 6½° south of **Gamma** (γ) **Cap** will easily reveal this globular cluster. Unfortunately, M-30 suffers from being the only object of its kind in Capricornus and is upstaged by many other brighter and more prominently located globulars.

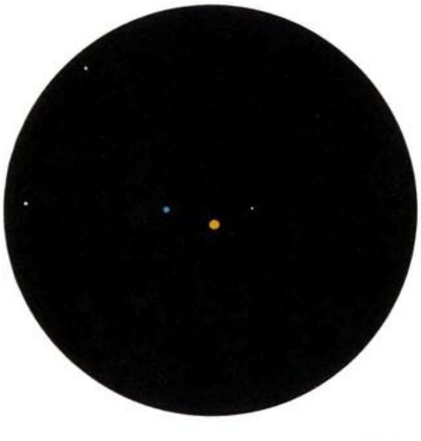
Here's how Messier described what he saw on the night of discovery in 1764: "It was a nebula seen with difficulty in an ordinary telescope of three and a half feet [focal length]. It is round and I saw no star there, having observed it with a good Gregorian telescope at 104x." This "nebula" was first resolved by Sir William Herschel in 1783. He described it as brilliant, with two rows of stars in a line.

The central nucleus is small and dense: about 1.5′ of arc in diameter. According to measurements made with the help of photographs, its extreme extent is 9′ of arc. Backyard observers usually see it as an 8.2 magnitude fuzz-ball about 6′ of arc in diameter. Although this isn't a showpiece globular, it is a fine object to conclude a relaxing evening of autumn observing.

Alpha Capricorni



Beta Capricorni

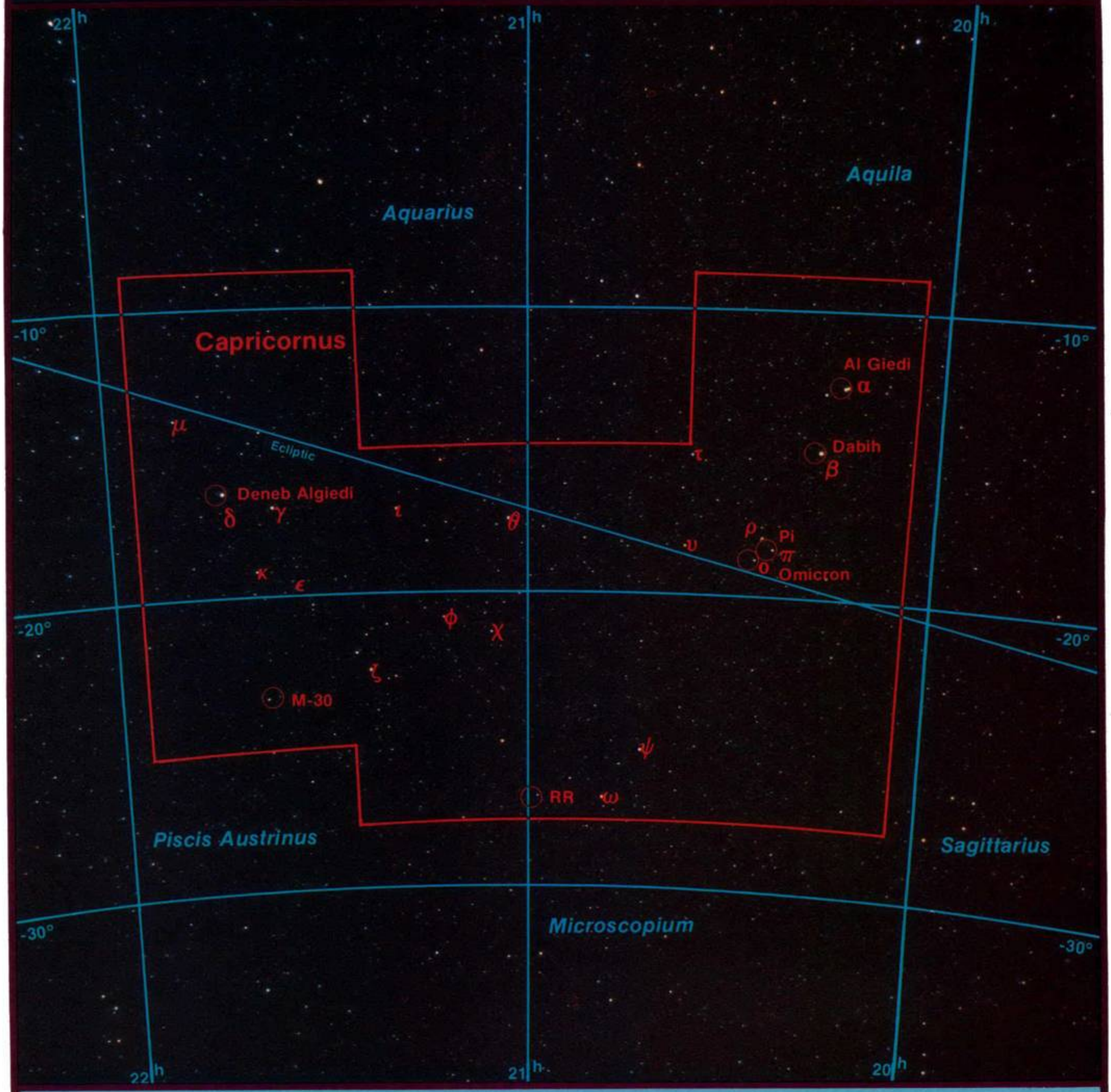


Drawings by James Mullaney

Photo by Robert Provin and Brad Wallis

capricornus

Map by Robert Burnham


22h
21h
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Aquarius
Aquila
-10°
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Capricornus
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RR
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Piscis Austrinus
Sagittarius
-30°
-30°
Microscopium
22h
21h
20h

Object	Type	Mag.	Size/Sep. Per.	R.A. (1950)	Dec.	R.A. (2000)	Dec.
Alpha (α^1)	★^{2}	4.5,9.0	46″	20h15m	-12°40′	20h18m	-12°31′
Alpha (α^2)	★^{3}	3.8,11.2,11.5	7″,1.2″	20h15m	-12°42′	20h18m	-12°33′
Beta (β)	★^{3}	3.2,6.2,10.0	205″,0.9″	20h18m	-14°56′	20h21m	-14°47′
Pi (π)	★^{2}	5.2,8.5	3.2″	20h24m	-18°23′	20h27m	-18°13′
Omicron (o)	★^{2}	6.1,6.6	22″	20h27m	-18°45′	20h30m	-18°35′
RR	m★	9.5-14.5	277d	20h59m	-27°17′	21h02m	-27°05′
M-30	●	8.2	6′	21h38m	-23°25′	21h40m	-23°11′
Delta (δ)	ℵ★	2.9-3.1	1.023d	21h44m	-16°21′	21h47m	-16°08′

★	*Star*
★^{2}	*Double Star*
★^{3}	*Triple Star*
m★	*Regular Variable*
∩★	*Irregular Variable*
ℵ★	*Eclipsing Variable*
○	*Open Cluster*
●	*Globular Cluster*
■	*Planetary Nebula*
□	*Bright Diffuse Nebula*
§0	*Elliptical Galaxy*
§S	*Spiral Galaxy*
§ʃ	*Barred Spiral Galaxy*
§#	*Peculiar/Irregular Galaxy*

W. TIRION
sky Atlas
2000.0
11
Great Orion N.
Horsehead N.
1982·M43
1976·M42
2068·M78
34·δ
50·ζ
48·σ
46·ε
36·υ
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